International Library of Technology
459

Steam Boilers and Equipment

317 ILLUSTRATIONS

By
C. B. LINDSTROM
AND I.C.S. STAFF
Prepared Under Supervision of
A. B. CLEMENS
DIRECTOR, MECHANICAL SCHOOLS
INTERNATIONAL CORRESPONDENCE SCHOOLS

TYPES OF STEAM BOILERS
BOILER MOUNTINGS
BOILER DETAILS
PIPES AND PIPE FITTINGS
BOILER FURNACES, SETTINGS, AND CHIMNEYS

Published by
INTERNATIONAL TEXTBOOK COMPANY
SCRANTON, PA.
1928

Printed in U. S. A.

PRESS OF
INTERNATIONAL TEXTBOOK COMPANY
SCRANTON, PA.
459

92715

PREFACE

The volumes of the International Library of Technology are made up of Instruction Papers, or Sections, comprising the various courses of instruction for students of the International Correspondence Schools. The original manuscripts are prepared by persons thoroughly qualified both technically and by experience to write with authority, and in many cases they are regularly employed elsewhere in practical work as experts. The manuscripts are then carefully edited to make them suitable for correspondence instruction. The Instruction Papers are written clearly and in the simplest language possible, so as to make them readily understood by all students. Necessary technical expressions are clearly explained when introduced.

The great majority of our students wish to prepare themselves for advancement in their vocations or to qualify for more congenial occupations. Usually they are employed and able to devote only a few hours a day to study. Therefore every effort must be made to give them practical and accurate information in clear and concise form and to make this information include all of the essentials but none of the non-essentials. To make the text clear, illustrations are used freely. These illustrations are especially made by our own Illustrating Department in order to adapt them fully to the requirements of the text.

In the table of contents that immediately follows are given the titles of the Sections included in this volume, and under each title are listed the main topics discussed.

International Textbook Company

B

CONTENTS

NOTE.—This volume is made up of a number of separate parts, or sections, as indicated by their titles, and the page numbers of each usually begin with 1. In this list of contents the titles of the parts are given in the order in which they appear in the book, and under each title is a full synopsis of the subjects treated.

TYPES OF STEAM BOILERS

Pages

Stationary, Marine, and Locomotive 1–86
Terms and Definitions 1– 2
Stationary Boilers 2–47
Shell, Flue, Tubular, and Water-Tube Types 2–22

Plain cylindrical, or shell, boiler; Flue boiler; Horizontal return-tubular boiler; Uniflow return-tubular boiler; Robb-Mumford boiler; Clyde, or Dry-back, boiler; Vertical tubular boiler; Manning boiler.

Semi-Portable and Portable Boilers 23–28

Distinctive features; Locomotive-type boiler; Wet-bottom firebox type; Pennsylvania boiler.

Horizontal Water-Tube Boilers 29–37

Advantages of water-tube boilers; Babcock and Wilcox boilers; Heine water-tube boiler; Edge Moor water-tube boiler.

Vertical Water-Tube Boilers 38–47

Bigelow-Hornsby water-tube boiler; Stirling water-tube boiler; Hazelton water-tube boiler; Wickes water-tube boiler; Cahall boiler.

Marine Boilers 48–81
Fire-Tube Marine Boilers 48–57

Scotch boilers; Single-ended Scotch boiler; Double-ended Scotch boiler; Advantages of Scotch boiler.

Gunboat boilers 57–60

Locomotive type for marine purposes; Tubular type.

TYPES OF STEAM BOILERS

(Continued)

Pages

Water-Tube Marine Boilers........................ 60–81

Types of water-tube marine boilers; Features of large-tube and small-tube boilers; Tube arrangements; Belleville water-tube boiler; Babcock and Wilcox marine boiler; Babcock and Wilcox box-type marine boiler; Babcock and Wilcox drum-type boiler; Thornycroft water-tube boiler; Thornycroft-Schulz water-tube boiler; Modified Thornycroft boiler with superheater; Yarrow water-tube boiler; Yarrow water-tube boiler with superheater; Normand water-tube boiler; White-Forster boiler.

Locomotive Boilers.............................. 82–86

Classes of locomotive boilers; Straight-top boiler with wide firebox; Extended wagon-top boiler with Belpaire firebox; Conical boiler with Jacobs-Shupert firebox.

BOILER MOUNTINGS

Safety Devices.................................. 1–35

Safety Valves................................... 1–19

Forms of Safety Valves.......................... 1–12

Purpose of safety valve; Classes of safety valves; Lever safety valve; Pop safety valves; Pop safety valves for stationary boilers; Safety valves for marine boilers; Locomotive-boiler safety valves; Use and care of safety valves; Safety-valve rules and regulations.

Safety-Valve Calculations....................... 13–19

Lever safety-valve calculations; Spring safety-valve calculations; Methods of checking safety-valve capacity.

Fusible Plugs................................... 20–22

Purpose of fusible plugs; Inside and outside fusible plugs; Rules for use of fusible plugs; Location of fusible plugs.

Water-Level Indicators.......................... 22–29

High- and low-water alarms; Gauge-cocks; Glass water gauges; Automatic safety water gauges; Water column; Water-column connections; Installation of gauge glasses, gauge-cocks, and water columns.

Pressure Gauges................................. 30–35

Steam gauge; Steam-gauge siphons; Testing steam gauges; Rules for installation and use of steam gauges.

Superheaters.................................... 36–40

Purpose of superheating; Wrought-iron superheater; Foster superheater; Elesco superheater.

BOILER DETAILS, PART 1

Pages

Fire-Tube and Water-Tube Boiler Details........... 1–49

Riveted Joints 1–25

Rivets and Riveting............................... 1– 3

Forms of Riveted Joints........................... 4– 9

Terms used in riveted work; Double- and triple-riveted lap joints; Single-riveted single-strap butt joint; Double-strap butt joint; Butt joints with straps of equal widths.

Arrangements of Riveted Joints.................... 10–18

Location of longitudinal seams in shell boilers; Location of longitudinal joints in internally fired furnaces; Connecting longitudinal lap joints at girth seam; Connecting single-strap butt joint and girth seam; Longitudinal seam at smokebox of locomotive boiler; Connecting double-strap butt joint and girth seam; Seam connections of shells of locomotive boilers; Arrangement of smokebox joints; Methods of making angular connections.

Arrangement of Firebox Joints..................... 19–25

Fire-door and mud-ring connections; Connecting sheets to mud-rings; Fire-cracks in joints.

Heads of Boilers and Drums........................ 26–29

Flat heads; Bumped heads.

Domes and Drums................................... 30–39

Steam domes; Steam drum; Mud-drums and blow-outs.

Openings in Boilers............................... 40–49

Steam, water, and washout openings; Manholes; Water and steampipe openings.

PART 2

Staying 1–20

Types of Stays and Braces......................... 1–20

Purpose and Classification........................ 1– 2

Types of Direct Stays............................. 2– 7

Solid screw staybolt; Screw staybolt with telltale hole; Screw staybolts with nuts; Through stays; Flexible staybolts; Stay-tubes.

Diagonal Stays 8–13

Radial stays; Flexible radial crown stays; Gusset stays; Diagonal stays.

Girder Stays 14–17

Girder stays in Scotch boilers; Locomotive-boiler crown bars.

BOILER DETAILS, PART 2—(*Continued*) *Pages*

Miscellaneous Braces 17–20
Throat braces; Steel angle stays.

Tubes, Flues, and Furnaces.............................. 21–36
Boiler Tubes and Flues.............................. 21–27
Boiler Tubes 21–26
Purpose of boiler tubes; Manufacture of boiler tubes; Sizes and gauges of boiler tubes; Upset tubes; Installation of boiler tubes.

Boiler Flues 27
Furnace Flues and Combustion Chambers.............................. 28–36
Cylindrical furnace flues; Corrugated furnaces; Combustion chambers.

PIPES AND PIPE FITTINGS

Pipes 1–29
Wrought Pipe 1– 8
Wrought-iron and mild-steel pipe; Commercial grades of wrought pipe; Galvanized pipe; Spiral jointed pipe.

Pipe Fittings 8–29
Materials for fittings; Pipe couplings; Pipe unions; Flange unions; Pipe flanges; Types of pipe flanges; Gaskets for flanges; Types of pipe joints; Expansion and contraction of pipes; Expansion joints; Pipe bends; Pipe coverings; Pipe supports; Flanged fittings.

Valves and Cocks.............................. 30–40
Globe valves; Angle valve; Gate valves; Automatic stop-valve; Check-valves; Blow-off valves and cocks; Pressure-reducing valves.

Steam-Piping Accessories 41–44
Separators; Classes of steam separators; Centrifugal separator; Baffle-plate separator; Drip pockets; Exhaust heads.

Steam Traps 45–50
Purpose of steam trap; Classes of steam traps; Bucket trap; Steam-trap connections; Tilting trap; Float trap; Thermostatic trap; Suggestions for trap installations.

Design and Arrangement of Piping.............................. 50–61
Principles of Design.............................. 50–52
General requirements; Drainage; Water hammer; Condensation and friction.

PIPES AND PIPE FITTINGS

(*Continued*)

Pages

Arrangement of Piping 53–59
General requirements; Connecting main steam pipe to boiler; Steam piping for small plant.

Single-Pipe and Double-Pipe Systems 59–61
Pipe Calculations 62–67
Steam-Pipe Sizes 62–65
Flow of steam in pipes; Velocity of steam in pipes; Supply pipes for steam engines; Sizes of main steam pipes; Friction of valves and fittings.

Flow of Water in Pipes 66–67
Finding size of pipe; Velocity of flow.

BOILER FURNACES, SETTINGS, AND CHIMNEYS PART 1

Furnaces and Steam Boilers 1–60
Furnace Design and Construction 1–18
Conditions Affecting Furnace Design 1– 5
Furnace volume; Furnace temperature; Effect of composition of coal on furnace volume; Firebrick arches and walls; Distance between boiler and grate.

Furnace and Ash-Pit Details 6–12
Furnace mouth; Bridge wall; Rear arch; Ash pits.

Special Types of Furnaces 13–18
Dutch oven; Hawley down-draft furnace; Burke furnace; Dorrance furnace; Wooley furnace.

Grates 19–26
Stationary Grates 19–23
Grate characteristics; Common form of fixed grate; Sawdust grate; Special forms of grate bars; Adapting grate to fuel; Installing stationary grate bars; Disadvantages of stationary grates; Grates for vertical boilers.

Shaking Grates 24–26
Settings for Steam Boilers 27–60
General Features 27–28
Foundations and walls; Firebrick.

Settings of Return-Tubular Boilers 29–35
Details of Brickwork 29–32
Forms of wall construction; General arrangement of boiler.

BOILER FURNACES, SETTINGS, AND CHIMNEYS

PART 1—(*Continued*)

Pages

Supports for Return-Tubular Boilers.................... 32–36

Columns; Cross-beams.

Settings of Water-Tube Boilers.................... 36

Methods of supporting boilers; Baffles.

Mechanical Stokers 37–60

Development and Classification.................... 37–39

Development of mechanical stoker; Advantages and disadvantages of stokers; Economic considerations; Classification of stokers; Finding size of stoker.

Overfeed Stokers 40–47

General construction of overfeed stoker; Roney stoker; Wilkinson stoker; Murphy automatic furnace.

Underfeed Stokers 48–52

Characteristics of underfeed stokers; Jones' underfeed stoker; Cleaning Jones stoker; American stoker.

Chain-Grate Stokers 53–57

Principle of construction; Green chain-grate stoker; Playford chain grate.

Stokers for Small Power Plants.................... 58–60

Coal-throwing devices; Hand-fired stokers.

PART 2

Boiler Settings 1–16

Settings for Burning Oil and Powdered Coal......... 1–12

Oil-Burning Furnaces 1– 8

Advantages of oil fuel; Furnace requirements for oil burning; Furnaces for oil burning; Oil furnace for Scotch boiler; Oil furnace for locomotive boiler; Adapting coal-burning furnaces for oil burning.

Equipment for Burning Powdered Coal............. 9–12

Preparation of powdered coal; Burning pulverized coal; Furnace design for burning powdered coal.

Reclaiming Waste Heat.......................... 13–17

Utilizing waste gases from kilns; Preheating air by flue gases.

Chimneys and Draft.............................. 17–52

Handling Flue Gases.............................. 17–34

BOILER FURNACES, SETTINGS, AND CHIMNEYS

PART 2—(*Continued*)

Pages

Breechings 17–20

Forms of breechings; Breeching design.

Types of Chimneys.................................. 21–28

Details of construction; Brick chimney; Reinforced-concrete chimney; Steel chimney; Guyed steel stacks.

Proportions of Chimneys.......................... 29–34

Requirements of chimney; Height of chimney; Area of chimney; Maximum combustion rate.

Draft 35–52

Methods of Producing Draft...................... 35–37

Natural draft; Measurement of draft pressure; Mechanical draft; Advantages and disadvantages of mechanical draft.

Equipment for Mechanical Draft.................... 38–42

Fans and steam jets; Typical forced-draft installations; Ash pit fixtures for forced-draft installations; Horsepower required for producing forced draft; Turbine blower; Induced-draft apparatus.

Draft Control 42–48

Balanced draft; Automatic damper regulators; Hand-operated draft regulator.

Other Draft-Producing Devices.................... 49–52

Steam jets; Argand blower; Induced draft by steam jet.

TYPES OF STEAM BOILERS

STATIONARY, MARINE, AND LOCOMOTIVE

TERMS AND DEFINITIONS

1. Introduction.—A steam boiler is a closed vessel that, when partly filled with water and heated, is used for the purpose of generating steam. The steam may be used for power, heating, or other purposes. The generation of steam for the development of power subjects the boiler to the most severe strains and requires the greatest refinement of design. The descriptions that follow are devoted to boilers representing the various types in general use.

2. The steam boiler, when in use, is partly filled with water, the space within it being thus divided into two parts, known as the steam space and the water space. The water-line is an imaginary line indicating the level to which the boiler should be kept filled when in service, in order that steam may be generated to best advantage. The *steam space* is the space in the boiler above the water-line. The *heating surface* of a boiler is that part of its surface exposed to the fire, and to the hot gases from the fire as they pass from the furnace to the chimney. The *furnace* is the part of a boiler installation in which the fuel is burned. The *fittings* of a steam boiler consist of such attachments as a steam gauge, water column, and safety valve. The steam gauge indicates the steam pressure in the boiler. The water column is a device composed of a glass tube called a water glass, and three gauge-cocks, called *try cocks*, that are used to determine the height of the water level. The safety valve is attached to the steam space of the

boiler; it automatically relieves the steam pressure when the pressure rises above that for which the valve is set.

3. Classification of Steam Boilers.—Steam boilers may be classified according to their form, construction, and use. Thus, according to their form, boilers are *horizontal* or *vertical;* according to their construction, they are *shell, flue, sectional, fire-tube,* or *water-tube boilers;* according to the different conditions under which they are used, they are designated as *stationary, locomotive,* or *marine boilers.*

A shell, or cylindrical, boiler is one consisting of a plain cylinder closed at both ends. A sectional boiler is one made up of a number of cast-iron sections that are assembled and bolted together. This type of boiler is chiefly employed for low-pressure heating purposes. A flue boiler is made up of a cylindrical shell having one or more large flues, or pipes, 6 inches or more in diameter, surrounded by water and so arranged that the hot gases must pass through the flues. A fire-tube boiler resembles a flue boiler in principle, but in it a large number of tubes take the place of the flues. The tubes are generally 5½ inches or less in diameter. The hot gases pass through these tubes just as they pass through the larger flues of a flue boiler. A water-tube boiler consists of a number of tubes connected to drums and so arranged that water circulates within them while the heating is done by the hot gases surrounding them. The main features of different types of boilers are frequently combined, giving rise to a large number of special forms.

STATIONARY BOILERS

SHELL, FLUE, TUBULAR, AND WATER-TUBE TYPES

4. Plain Cylindrical, or Shell, Boiler.—The plain cylindrical, or shell, boiler is now rarely used; but because it is of simple construction, it will be described, to bring out certain general features that are common to many boilers. It is not economical on account of its small heating surface. Its advan-

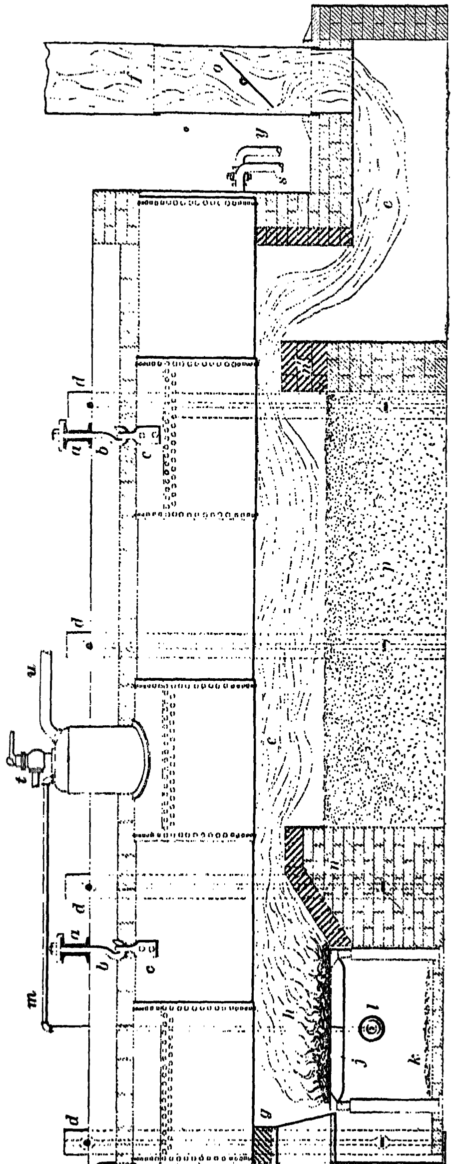


FIG. 1

tages are: Simplicity of construction, low first cost, and the ease with which it may be cleaned and repaired. Its disadvantages are: Low efficiency, which causes waste of fuel, especially if the boiler is pushed beyond easy steaming capacity; large space occupied; its length, which makes it difficult to support without creating excessive and dangerous strains in the sheets and riveted joints, or seams, due to the weight of the boiler and water and the pressure of steam, and to unequal expansion and contraction. These strains change in amount, from tension to compression and vice versa, and may become very dangerous, resulting possibly in a rupture of the boiler.

5. A plain cylindrical boiler, Figs. 1 and 2, consists essentially of a long cylinder, or shell, made of

iron or steel plates riveted together, the girth seams having a single row of rivets and the longitudinal seams a double row of rivets. The shells of boilers of this type are usually from 30 inches to 40 inches in diameter, and from 20 feet to 40 feet in length, although in some cases the length has been made as great as 70 feet. The *heads,* or ends, of the cylinder are either hemispherical or flat. The former are more generally used, as they are stronger than flat heads and require no bracing. The manner of suspending the shell is clearly shown. The boiler is

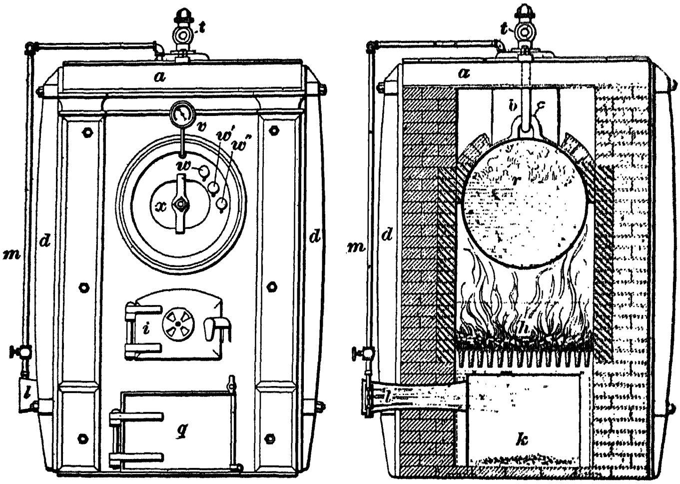


FIG. 2

supported and enclosed by side walls of brick, known as the *boiler setting.* The channel beams *a* are laid across the brick side walls, and the boiler is suspended from the beams by means of the hooks *b* and eyes *c,* the latter being riveted to the shell.

6. The side walls are supported and prevented from buckling by the *binders,* or *buckstaves, d,* Fig. 2, bolted together at the top and at the bottom. The buckstaves are cast-iron bars of **T** section. The eyes *c* are placed about one-fourth of the length of the shell from each end. This method of suspension allows the shell to expand and contract freely when heated or cooled.

The rear wall is built around the rear end of the shell, as shown in Fig. 1, and continued back to form the chamber *e*, into which opens the chimney or stack *f*. The *boiler front*, shown in Fig. 2, is of cast iron. Fig. 1 shows the front in section. The front end of the shell is partly surrounded by the firebrick *g*, but the weight of the shell comes on the hooks *b*, the rear wall and the firebrick *g* simply keeping the shell in position. The furnace *h*, Fig. 2, is placed under the front end of the boiler shell. The fuel is thrown in through the furnace door *i* and burns on the grate *j*, the ashes falling through the grate into the ash-pit *k*. To insure a supply of air sufficient for a more rapid combustion of the fuel than obtains under natural draft, the furnace is sometimes provided with a blower *l*, consisting of a cylinder leading into the ash-pit *k*, into which is led a jet of steam through the pipe *m*. The steam rushes into the ash-pit with great velocity and carries a quantity of air with it. The pressure of the air in the ash-pit is thus increased, more air is forced through the fire, and the combustion of the fuel is more rapid and complete. It is more usual, however, to use a fan blower instead of a direct steam jet for supplying additional air.

7. Behind the furnace, as shown in Fig. 1, is built the brick *bridge wall n*, which serves to keep the hot gases in close contact with the under side of the boiler shell. As boilers of this type are generally quite long, a second bridge wall *n′* is usually added. The gases arising from the combustion of the fuel flow over the bridge walls *n* and *n′* into the chamber *e*, and escape through the chimney *f*. The flow of the gases is regulated by the damper *o* placed in the chimney. The space *p* between the bridge walls is filled with ashes or some other good non-conductor of heat. The door *q* in the boiler front gives access to the ash-pit for the removal of the ashes. The tops of the bridge walls, the inner surfaces of the side and rear walls, and, in general, all portions of the brickwork exposed to the direct contact of the hot gases, as shown by the dark section lining, are made of a special kind of refractory brick that withstands a very high temperature.

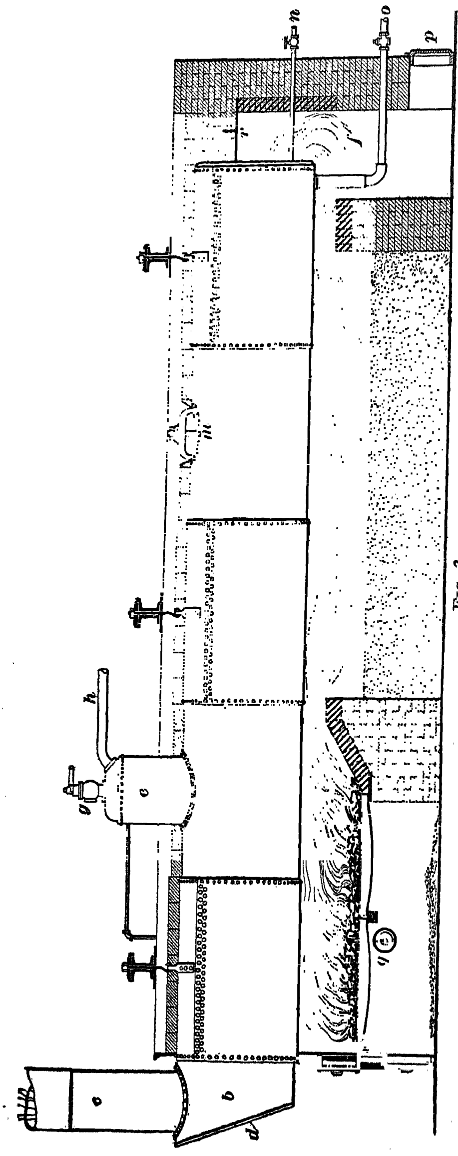


Fig. 3

The brickwork covers the upper portion of the boiler shell in such a manner as to prevent the hot gases from coming into contact with the shell above the water-line *r*, Fig. 2. The top of the shell is covered by brickwork or some other non-conducting material to prevent radiation of heat. Water is forced into the boiler through the feedpipe *s*, Fig. 1, from a pump or an injector. When in operation the water stands at about the level *r*, the space above being occupied by the steam.

8. The safety valve is shown at *t*, Fig. 1. It opens automatically when the pressure reaches the point for which the valve is set, and allows enough steam to escape so that the pressure will not rise above the desired point. Steam is taken from the boiler

through the steam pipe *u*. The steam gauge *v* indicates the pressure of the steam in the boiler; it is attached to a pipe that passes through the front head into the steam space. The gauge-cocks *w*, *w'*, and *w''*, Fig. 2, placed in the front head of the shell, are used to determine the water-level. If any one of the cocks is opened and water escapes, it is evident that the water-line is above that cock, while if steam escapes, the level must be below it. The *manhole* *x* is a hole in the front head through which a man may enter and inspect or clean the boiler; it is closed by a plate and yoke. To permit

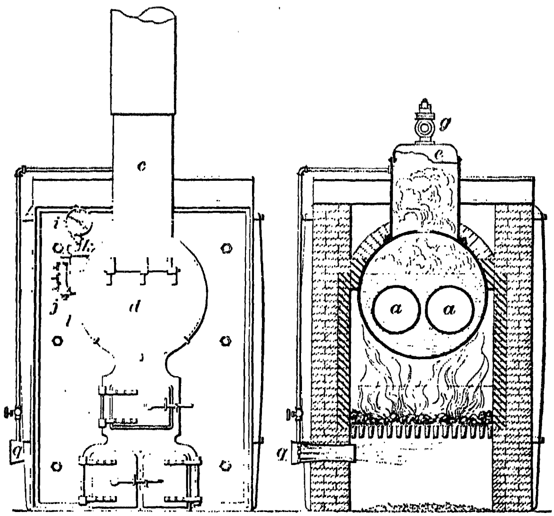


FIG. 4

the boiler to be emptied, it is provided with a *blow-off pipe* *y*, Fig. 1, through which the water and sediment may be discharged.

9. Flue Boiler.—The flue boiler differs from the plain cylindrical boiler in having one or more large flues running lengthwise through the shell, below the water-line. Such a boiler is shown in elevation and section in Figs. 3 and 4. The ends of the flues *a* are fixed in the front and rear heads of the shell. The front end of the shell is prolonged beyond the head, forming the *smokebox* *b*, which opens into the smokestack *c*. The

front of the smokebox is provided with a door *d*. The boiler shell is also provided with the *dome e*, which forms a chamber where steam may collect and free itself from its entrained water before passing to the engine. The manner of supporting the shell and the construction of the furnace and bridge walls are the same as for the plain cylindrical boiler. The hot gases, however, pass over the bridge walls to the chamber *f*, and then back through the flues *a* into the smokebox *b* and out of the stack *c*. It is plain that the heating surface is greater than that of the plain cylindrical boiler by the cylindrical surfaces of the flues *a*.

The boiler has a cast-iron front, to which the furnace door and ash-pit doors are attached. The safety valve *g* is attached to the top of the dome. The steam pipe *h* leads from the dome to the engine. The steam gauge *i* and gauge-cocks are placed on a column *j* that communicates with the interior of the shell through the pipes *k* and *l*, the former entering the steam space and the latter the water space. The manhole *m* is placed on top of the shell instead of in the head. The feedpipe is shown at *n*, and the blow-off pipe at *o*, both passing through the rear wall. Access is given to the rear end of the shell and to the pipes *n* and *o* through the door *p*. This form of boiler may be provided with a blower, as shown at *q*. The setting is built and supported in about the same manner as that shown in Fig. 1. The cast-iron *flue plate r* rests on the side and rear walls and supports the brickwork above it.

10. Horizontal Return-Tubular Boiler.—The return-tubular boiler is so largely used in the United States that it is regarded as the standard American fire-tube boiler. When properly constructed and operated it is very efficient. It is a modification of the flue boiler, the flues being replaced by tubes that are smaller and more numerous than the flues, usually ranging in size from 2½ to 4 inches in diameter. The greater part of the heating surface is provided by the tubes. Less space is required for the installation of this type, as compared with the shell boiler or the flue boiler of equal steam-generating capacity.

A horizontal return-tubular boiler and its setting are shown in perspective in Fig. 5. A part of the setting and the boiler front *a* have been broken away in order to show the construction clearly. The tubes extend the whole length of the shell and their ends are expanded into holes in the boiler heads and beaded over; sometimes they are welded to the heads after being beaded. A smokebox *b* is formed at the front of the boiler by brickwork, the arch *c* separating the smokebox from the furnace. The connection from the top of the smokebox to the chimney is generally made by a sheet-iron flue, although

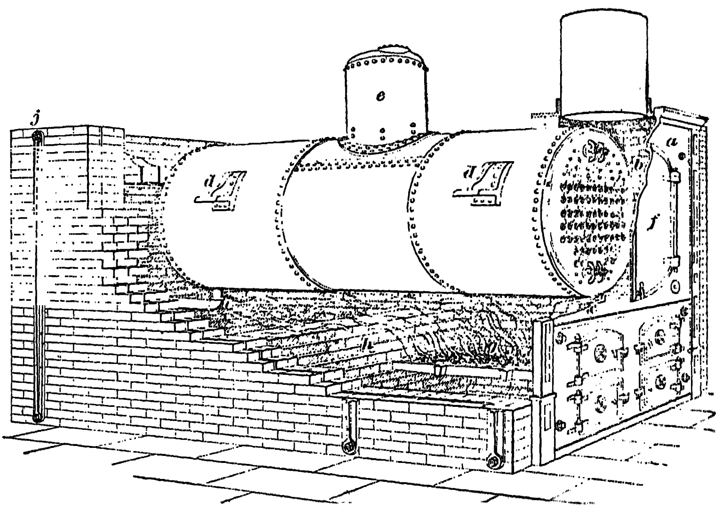


FIG. 5

occasionally a brick flue leading to the chimney is built on top of the boiler. The boiler is supported on the brick walls of the boiler setting by the brackets *d* riveted to the shell. These brackets usually rest on cast-iron plates let into the brickwork, rollers being set between the brackets and plates to allow the boiler to expand freely. A dome *e*, which increases the steam space, may be provided, though it is usually left off and an internal dry pipe is used instead. The walls are built and supported by buckstaves in practically the same manner as those previously described.

11. Firebrick is used for all parts of the wall exposed to the fire or heated gases. The fittings are not shown in Fig. 5. The safety valve is placed on top of the dome, and the pressure gauge and gauge-cocks are placed on the front. The manhole may be either in one of the heads or on top of the shell, although sometimes manholes are provided in both ends and in the top of the shell. The feedpipe may enter the front head, while the blow-off pipe *i* is placed at the bottom of the shell, at the rear end. Access is given to the rear end of the boiler through a clean-out door. The tubes are made accessible for cleaning out, etc., by large doors, as *f*, in the boiler front. The furnace and grates *g* are placed under the front end of the boiler. The gases pass over the bridge *h*, along under the boiler into the chamber at the rear, then back through the tubes to the smokebox *b*, and thence to the chimney.

12. Horizontal return-tubular boilers are installed with either *flush fronts* or *overhanging fronts*. These fronts are made of cast iron, or of steel plate formed into the shape for the doors, door frames, and rings that are used for supporting the smokebox doors. In the flush front setting, Fig. 5, the boiler does not extend beyond the boiler front. It is set back of the cast-iron front *a*, so that the gases have a large smoke space *b* to travel through before entering the stack.

The general arrangement of a return-tubular boiler having an overhanging front is shown in Fig. 6 (*a*). In this case the boiler has a steel smokebox *a* that extends beyond the steel front *b*. In such construction the front tube-sheet is installed so that the flange of the tube-sheet *c* extends outwards, as shown in view (*b*). This drawing further illustrates the relative arrangement of the tubes *d* and the diagonal braces *e* that support the flat section of the tube plate, above the tubes, commonly referred to as the *tube-head segment*. The stays are riveted to the boiler shell and tube head. The nozzle *f* is pressed from steel plate, having at the bottom a flange by which the nozzle may be riveted to the shell plate. The upper end of the nozzle has a flange to which the safety valve is bolted. To provide an entrance to the shell for inspection, for clean-

ing, and for the removal of tubes and their installation in case repairs are needed, the boiler is fitted with a manhole *g*, at

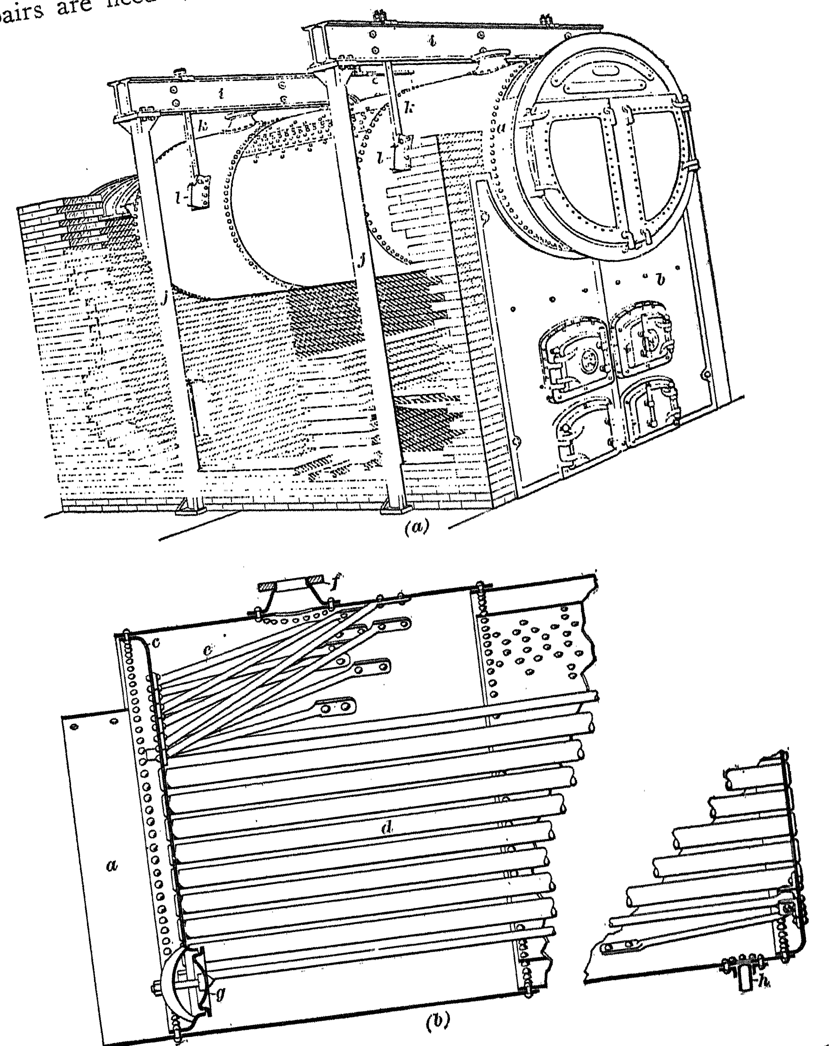


FIG. 6

the bottom of the front tube head. A manhole is also installed at the top of the boiler shell. At the rear of the boiler is

located a drain, or blow-off, *h*, that is employed for removing the water from the boiler periodically and for cleaning purposes. The boiler shown in view (*a*) is suspended from **I** beams *i* that are supported by cast-iron columns *j*. Suitable hanger rods *k* and hanger straps *l* are employed in suspending the boiler. This method of setting a boiler is more flexible than is obtainable with the use of brackets. The rear end is

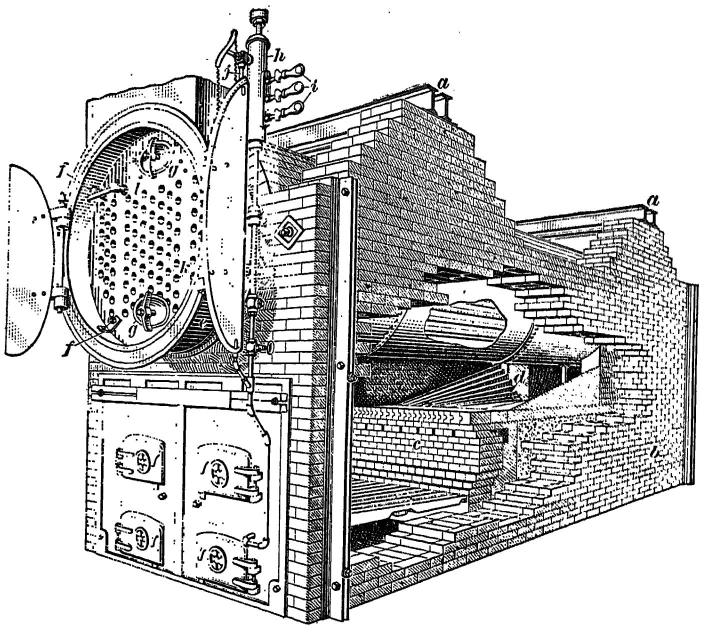


FIG. 7

set from 1 inch to 1½ inches lower than the front end to facilitate draining off the water through the blow-off at the rear.

13. Uniflow Return-Tubular Boiler.—The uniflow boiler is a modification of the horizontal return-tubular boiler. In Fig. 7 is shown a typical installation, with the boiler setting. The boiler is suspended from **I** beams *a* by suitable hangers. A brick setting *b* surrounds the boiler and forms the sides of the furnace. The furnace setting consists also of a bridge wall *c*, and an inverted arch *d* that runs from the bridge wall

to the rear of the boiler. This feature in the arch construction increases the velocity of the gases and causes them to flow in contact with the bottom of the shell plate of the boiler. The extension smokebox *e* is a steel-plate ring, fastened to the front head of the boiler by lugs *f* that are bolted to both the smokebox and the boiler head. This construction permits the removal of the smokebox, if repairs are required on the boiler head, or in case some of the tubes must be removed and new ones installed. To provide means for cleaning, inspecting, and

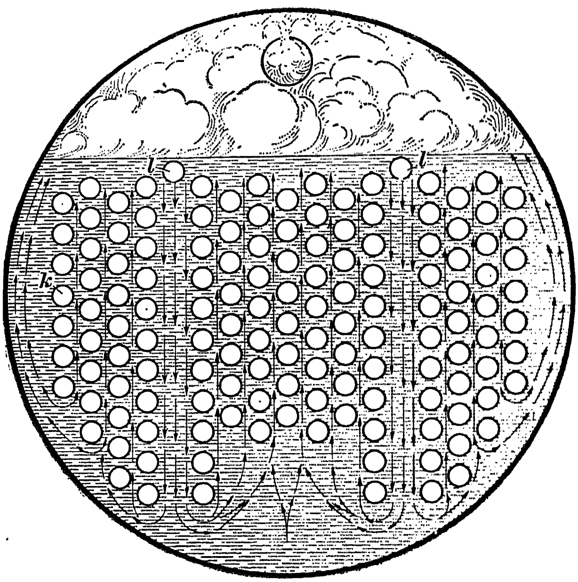


FIG. 8

repairing the boiler, manholes *g* are installed above and below the tubes. A water column *h*, with gauge-cocks *i* and a gauge glass *j*, is conveniently placed at the front of the boiler, so that the water level in the boiler can be readily seen.

14. The tubes *k*, Fig. 7, shown also in the cross-section, Fig. 8, are arranged in parallel vertical rows, but are staggered in the horizontal alinement. They are grouped in three divisions, thus forming an arrangement called *tube nests*, or *tube banks.*

The water is fed into the boiler through the connection *l*, placed on the side of the front head above the tubes. The feedwater is discharged downwards between the center and outer tube banks. Circulation of the water and steam is indicated by the arrows. Steam rises directly from the heating surface to the steam space and the cooler water flows downwards between the tubes and replaces the hotter water carried away by the upward circulation. The boiler derives its name from this provision for the circulation of the water.

15. Robb-Mumford Boiler.—The boilers so far described have the furnace outside of the boiler itself, and hence are said

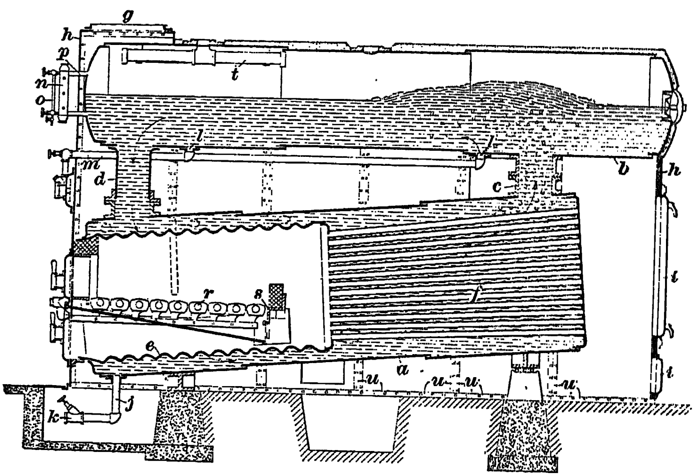


FIG. 9

to be *externally fired*. Many boilers are in use, however, in which the furnace is inside the boiler; such boilers are referred to as being *internally fired*. The Robb-Mumford boiler, shown in section in Fig. 9, is an example of an internally fired horizontal boiler. It consists of two cylindrical drums *a* and *b* connected by the cylindrical nozzles, or necks, *c* and *d*, one at each end. The lower drum *a* contains a cylindrical furnace *e* fitted at one end with a furnace front containing a fire-door and an ash-pit door, and at the other end with a tube-sheet into which are expanded the tubes *f*. The tubes are also expanded into the

rear head of the lower drum *a*. The lower drum is inclined about 1 inch per foot, this inclination promoting the circulation of the water in the boiler, and also facilitating the complete emptying of the boiler, as the blow-off pipe is attached to the lower end of the lower drum *a*. The upper drum *b* serves as a steam drum. The gases of combustion pass from the furnace through the tubes *f* and return about the lower and upper drums, passing then to the smoke outlet *g* at the front of the boiler. A steel casing *h*, containing suitable doors *i* that give access to the interior, surrounds both the upper and lower drums.

16. An important factor in the operation of a boiler is the circulation, or movement of the water. When the water is heated, it expands, becomes lighter, and rises to the surface. In the boiler shown in Fig. 9, the heated water strikes the sloping upper surface of the lower drum *a* and flows toward and up through the neck *c*. When the water begins to boil, the steam bubbles up through the water, forming a mixture of steam and water. This condition increases the rapidity with which it rises through the neck *c*, and the more rapid the boiling, the more rapid the circulation becomes. When the mixture reaches the surface of the water, the steam separates and accumulates in the drum *b*, above the water level. As the mixture rises through the neck *c*, water takes its place in the lower drum, and the neck *d* is provided for this purpose. Therefore, as the water and steam rise through the neck *c*, the water descends from the upper to the lower drum through the neck *d*, thus completing the circulation.

17. The blow-off *j*, Fig. 9, is located at the front of the boiler, and when the blow-off valve *k* is opened the water and steam will be carried through a pipe to the outside of the boiler room or into a sewer. The purpose of the bottom blow-off is to remove mud and sediment that collect at the bottom of the boiler. Feedwater enters through the openings *l*, and the outside water pipe *m* is led to the discharge end of a feedwater pump or injector. The water column *n* and the gauge glass *o* are joined to the boiler by the pipes *p*. The upper pipe enters the steam space and the lower pipe the water space. This

arrangement of the devices and piping makes it possible to determine the height of the water level in the boiler at all times. The rocking grates *r* in the boiler furnace are supported at the rear by an arch *s* and at the front by an angle-iron support. A pipe *t*, called the *dry pipe*, is connected to the main steam outlet. It is of cylindrical shape, from 4 to 6 inches in diameter, having a number of holes along the top, through which steam enters in its travel to the steam outlet. The purpose of the dry pipe is to remove water held in suspension in the steam. The casing that surrounds the boiler is built of steel plate with angle-iron stiffeners *u*, and is made in sections that are bolted together. The inside of the casing and the top of the steam drum are lined with non-conducting material.

18. Clyde, or Dry-Back, Boiler.—The Clyde boiler shown in Fig. 10 is entirely self-contained, requiring no brick setting. It was originally designed for marine use, but on account of the small space it occupies it is used in many stationary steam plants. This type of boiler has a very large amount of heating surface in proportion to its grate area. The boiler consists of a large cylindrical shell *a*, its ends being closed with flat heads *b*. The corrugated furnace *c*, commonly referred to as the *Morison corrugated furnace*, is riveted to the front and rear heads, which are flanged inwards for this purpose. Tubes *d* extend from head to head, thus providing heating surface and a means for conveying the gases from the furnace to the uptake or smokestack *e* that connects with the chimney *f*. The smokebox is also commonly called a *breeching*. The flat heads are stayed by end-to-end stays *g* called *through stayrods*, which prevent bulging of the heads. The remaining parts of the flat heads are supported by the tubes, which are expanded and beaded over, and by the furnace flue. The furnace is formed within the flue, and comprises the grate *h*, the ash-pit *i*, and the bridge *j*. The gases of combustion flow to the rear into the combustion chamber *k* and then pass through the tubes to the front and into the uptake *e*.

19. The combustion chamber *k*, Fig. 10, is formed by a thin cylindrical shell attached to the rear end of the boiler, and

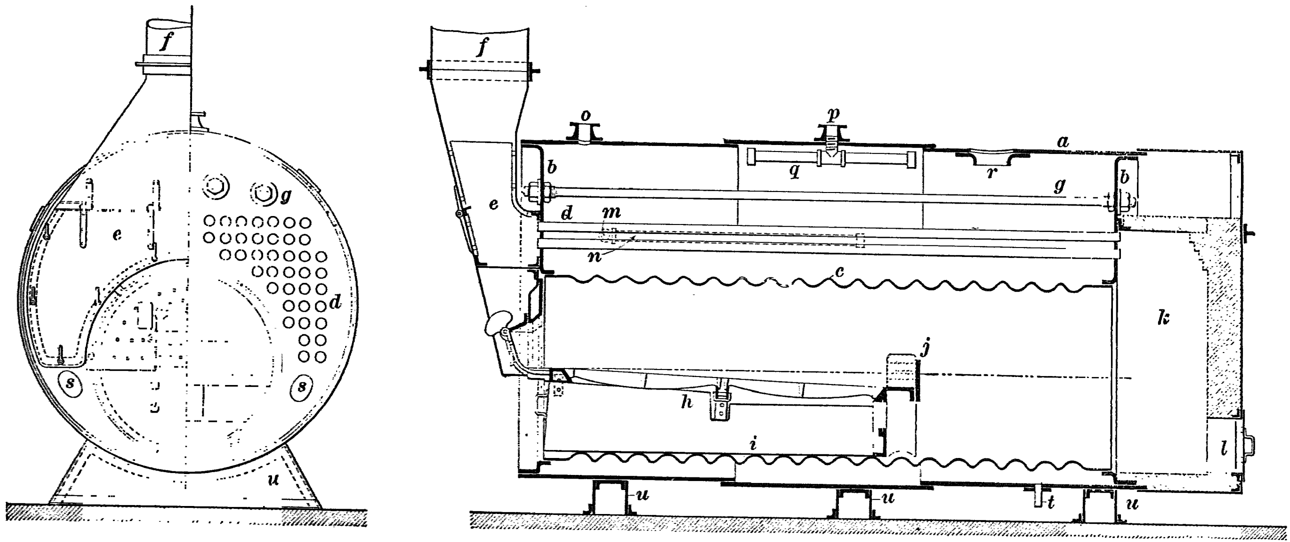


FIG. 10

is lined with firebrick or thick asbestos millboard, which is light and is not affected by intense heat. The back plate is removable, giving access to the rear ends of the tubes. A door *l* gives access to the combustion chamber for the removal of ashes and soot and for the purpose of examination and repair. The feedwater enters the boiler at *m* and, passing through the internal perforated feedpipe *n*, is discharged downwards alongside the shell in small streams. The various fittings, such as the steam gauge, water column, and safety valve, are not shown in the illustration. The water column and steam gauge would be located conveniently for reading the steam pressure and for determining the water level. The safety valve would be bolted to the nozzle *o*, and the steam pipe to the nozzle *p*. The steam is collected by the dry pipe *q*, which is effective in removing water mixed with the steam. The manhole is placed in the shell at *r*, and handholes are arranged in the front head, at *s*. The blow-off connection is placed at *t*. The boiler is supported by structural members *u*, made of angle iron and plate, and so arranged that each one carries approximately the same weight.

20. Vertical Tubular Boiler.—The vertical, or upright, fire-tube boiler may be considered as a modification of the locomotive type placed on end, and, in common with that type, is self-contained. It has the advantage that it requires less floor space than the horizontal return-tubular type; and, being self-contained, the outer shell can be made as heavy as desired for any working pressure. Vertical boilers are used to supply steam for hoisting engines, power shovels, and other installations requiring a small, compact boiler. The large sizes are employed for power purposes in some of the large power plants; but as a rule the vertical boiler is rather inefficient and hard to keep free from soot. Leakage of upper tube ends often occur, owing to forcing.

21. A common form of vertical boiler is shown in Fig. 11. It consists of a vertical shell, at the lower end of which is the firebox *a*. The lower rim of the firebox and the lower end of the shell are separated by a wrought-iron ring *b*, commonly

called a *mud-ring.* Both shell and firebox are riveted to the ring, the rivets extending through both plates and the ring. For the larger sizes of boiler, the shell is made up of a number of cylindrical sections that are riveted together; or, as in the illustration, where a large firebox is required, the lower section of the boiler shell is joined to the smaller upper section by a taper course *c.* By this arrangement a large water space is obtained at the bottom of the shell between the tubes and the shell plate; also, it is easy to get at the tubes *d* and the tube-sheet *e,* commonly called *crown sheet,* for inspection and cleaning purposes. Entrance to the boiler is gained through the manhole *f.* Handholes *g,* conveniently arranged for cleaning purposes, are placed just above the tube-sheet and the mud-ring.

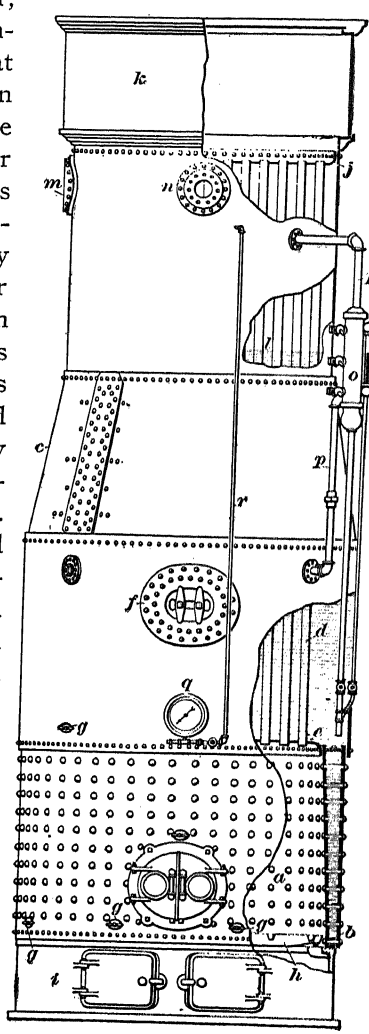


FIG. 11

22. The lower outer shell and the firebox, Fig. 11, are stayed together with threaded stays, called *staybolts,* which are screwed into both shell plates, so that the ends extend about $\frac{3}{16}$ inch from the boiler plates. To increase the holding powers of the stays, they are headed at the ends. The boiler shell and the grates *h* rest on a cast-iron base *i* that forms the ash-pit. The vertical tubes extend from the top tube-sheet *j* to

the crown sheet of the firebox. The tubes serve as stays to strengthen the flat surfaces of the tube-sheets, and convey the gases from the firebox to the chimney or stack connection *k*. The tubes pass through the steam space and are, therefore, not surrounded by water, as the highest water level is usually at the line *l*. This arrangement is considered a bad feature, because the tubes are liable to become overheated and collapse, when the boiler is forced. On the other hand, the steam temperature in the steam space is increased and drier steam is obtained, as the heat from the tubes slightly superheats the steam; that is, it heats the steam to a higher temperature than that of the water from which the steam is formed. The main steam-pipe connection is made to the flange *m* and the safety valve is bolted by a suitable fitting to the flange *n*. The water column *o*, with its gauge glass and cocks, is connected by the pipes *p* to the steam and water spaces of the boiler. A steam gauge *q* is connected to the steam space by a drop pipe *r* so that the gauge is brought to a suitable position for reading the pressure.

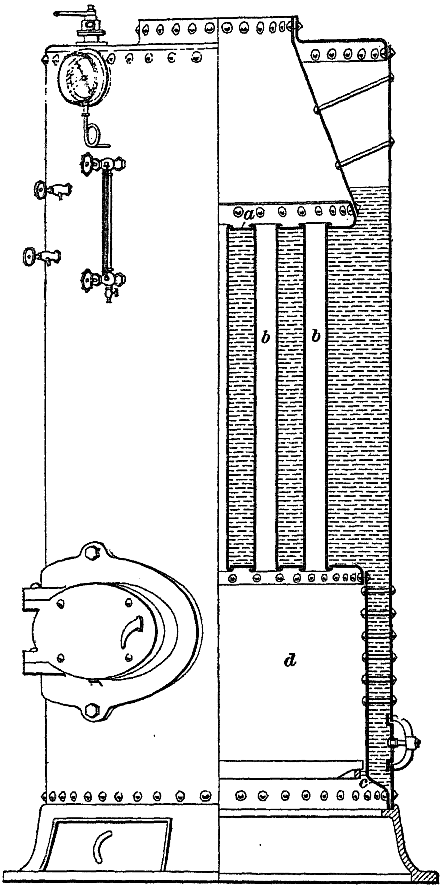


FIG. 12

23. The *submerged-head vertical boiler*, shown in Fig. 12, takes its name from the arrangement of the tube-sheet *a* and the tubes *b*. The tube-sheet *a* forms the base of the smokebox, and the upper ends of the tubes are expanded into it. By the use of the conical smokebox the tubes are entirely surrounded by water. Aside from the submerged head and the construction used in riveting the firebox and the outer shell together, the boiler is similar to the type shown in Fig. 11. The firebox *d*, Fig. 12, is flanged at its base so that the plate forms a compound curved section *c*, called an *ogee flange*. By making the flange of this shape, the necessary water space between the firebox and the outer shell is obtained. This space is usually referred to as the *water leg* of the boiler. Boilers made in this way are generally used for low working pressures and for light duty, as for hoisting engines. Vertical boilers of the form shown in Fig. 11 are employed in power plants, as such boilers are much larger and can, therefore, produce greater amounts of steam for power.

24. Manning Boiler.—The Manning boiler is used extensively throughout the New England States. In general, it is a modification of the plain vertical boiler having a tapering course. The details of its construction are shown in Fig. 13. The firebox *a* is a steel cylindrical shell, riveted to the tube-sheet or crown sheet *b* at the top, and to the mud-ring *c* at the bottom. An outside shell plate *d* surrounds the firebox and the two are connected by the staybolts *e*. To connect the upper shell *f* and the lower shell *d* of the boiler, an ogee flange *g* is employed. The advantage of the ogee connection is that it provides a larger firebox area without a corresponding increase in the diameter of the shell *f*, and does not require staying, being self-supporting on account of the double curvature of the plate. The tubes are of standard size, $2\frac{1}{2}$ inches in diameter, and are installed in lengths up to 20 feet. All tubes are held in the tube-sheets by expanding or rolling. The ends of the tubes extend usually from $\frac{3}{16}$ to $\frac{1}{4}$ inch beyond the head. They are turned down around the tube holes and beaded; that is, the tube ends are turned over to form rounded flares, or

lips, called beads. The beads prevent the tube ends from burning off and add strength to the staying qualities of the tubes.

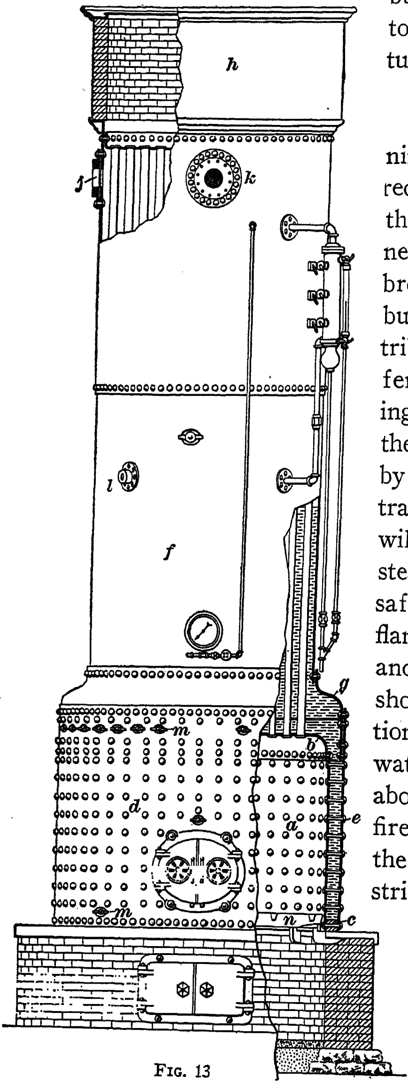


FIG. 13

25. The gases in the Manning boiler, Fig. 13, travel directly from the firebox through the tubes to the smoke connection *h*. The small tubes break up the products of combustion and give a wider distribution of the heat and transfer it rapidly to the surrounding water. The upper ends of the tubes are not surrounded by water, and the heat that is transmitted through these parts will superheat the steam. The steam outlet is at *j*, and the safety valve is connected to the flange *k*. The water column and steam gauge are also shown in their proper positions on the boiler. The feed-water connection *l* is well above the crown sheet of the firebox, being so placed that the colder water does not strike the heated plates of the firebox. Handhole openings *m* are provided in the shell above the crown sheet of the firebox and just above the mud-ring. They are used when it is necessary to clean out the mud and scale that collect on the tube-sheet and the mud-ring. The grates *n* rest

on a support incorporated with the brick foundation that forms the ash-pit. The vertical type of boiler requires considerable head room for its installation; but as compared with other boilers of the same size or capacity it occupies less ground space. To prevent heat losses by radiation from the outer shell, a covering of asbestos or magnesia should be applied.

SEMI-PORTABLE AND PORTABLE BOILERS

26. Distinctive Features.—It is somewhat difficult to draw a sharp line of demarcation between stationary, semi-portable, and portable boilers. Generally speaking, a *stationary boiler* is one that is permanently set in brickwork, as, for instance, the horizontal return-tubular boiler.

A *semi-portable boiler* is one that is arranged to be shipped on skids from place to place. It may, of course, be set on a permanent foundation; but it is then spoken of as a stationary boiler of the semi-portable type.

A *portable boiler* is a boiler mounted on wheels and that can be hauled by horses or tractors from place to place. Boilers of this kind are used by building contractors, quarrymen, threshermen, oil-well operators, etc. They are especially suitable to meet conditions requiring a temporary power plant capable of being moved about at a small expense.

Both semi-portable and portable boilers are generally of the firebox type, of either the vertical or the modified locomotive types.

27. Locomotive-Type Boiler.—The internal-firebox boiler of the locomotive type, shown in Fig. 14, is a modification of the larger types used for locomotives in railroad practice. With the exception of the horizontal return-tubular boiler, the locomotive-type boiler is used to a larger extent than any other type of fire-tube boiler. It is employed for tractors, road rollers, threshing machinery, and power plows, and for stationary purposes. The boiler consists of a cylindrical shell *a* that is riveted to a steel-plate firebox containing the furnace *b*. The firebox, which may be made in various shapes, is composed of a

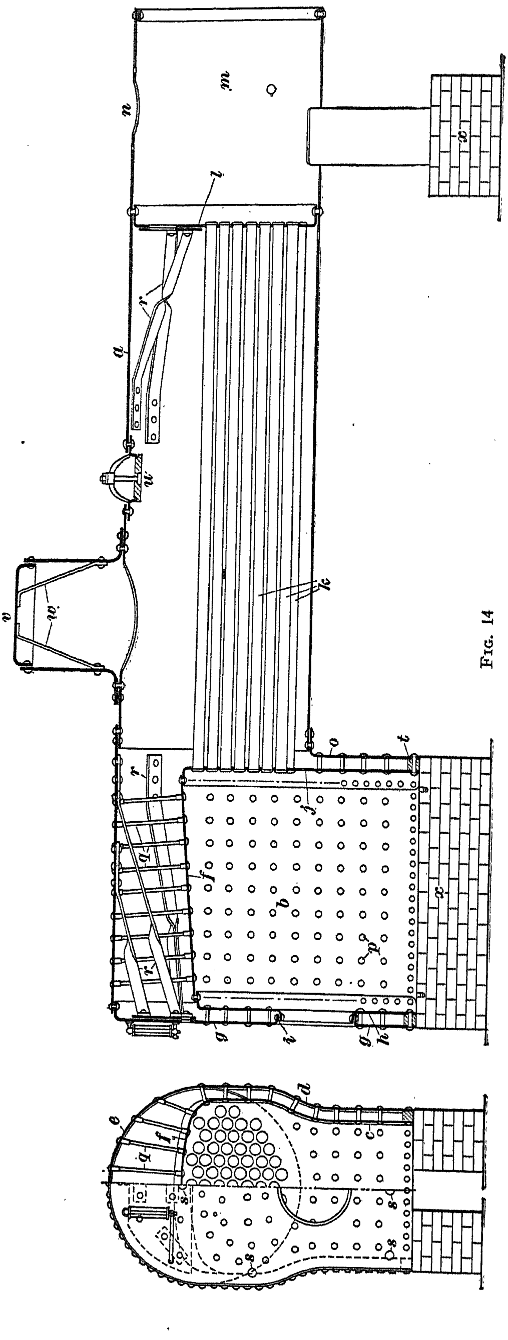


FIG. 14

continuous inner sheet *c* and an outer sheet *d*, called *wrapper sheets*. These sheets are arranged to leave water spaces, or water legs 2 to 3 inches in width at the sides of the firebox. The upper plate section *e* of the outer wrapper sheet is called the *roof*, and the top section *f* of the inside wrapper is known as the *crown sheet*. The end section of the outer wrapper is closed by a flanged head *g*, called the *back head*, and the inside wrapper sheet with a flanged head *h*, known as the *door sheet*. Both of these heads are flanged, as shown at *i*, to form the door opening, or *door ring*. The forward end of the inside wrapper sheet is closed with a flanged head *j*, called the *firebox tube-sheet*, from which a series of tubes *k* extend to the circular tube-sheet *l*. The front of the shell *a* is extended beyond the tube-sheet *l* to form the smokebox *m*. An opening *n* is cut in the smokebox for the stack connection. A flanged sheet *o*, known as the *throat sheet*, is so made that it connects the flat sides of the outer wrapper sheet of the firebox and the shell *a*.

28. As the flat sides of the furnace, Fig. 14, are not self-supporting, they must be braced or stayed. This is done by staybolts *p*, which are riveted over at both ends, so as to upset the stays in the threaded holes and thus produce steam-tight work. The stays *q* are known as *radial stays*, or *crown stays*, and support the roof and the crown sheet of the firebox. The flat surfaces of the back head *g* above the door ring, and that above the tubes of the front tube-sheet *l*, are stayed by diagonal braces *r*, called *crow-foot braces* on account of the shape of their ends. Circular clean-out openings *s* are provided above the mud-ring *t* and the crown sheet for washing out the boiler. The mud-ring *t* closes the water legs at the bottom of the firebox, being riveted to both the inner and outer wrapper sheets.

Entrance to the boiler for inspection, repairs, and cleaning is made by removing the manhole cover *u*. A dome *v* is attached to the shell *a*, but in some constructions it is riveted to the roof sheet. It is preferable, however, from the view-point of staying the firebox, to have the dome on the shell. The dome head, being flat, is not self-supporting, so it is stayed with crow-foot braces *w* that are riveted to the dome head and near the base of

the dome. In some constructions, threaded stayrods are screwed into the dome head and the shell plate under the dome; but in such a case the dome opening would not be cut out entirely as is shown in the illustration. A number of circular holes would be drilled in the shell plate, to allow free circulation of steam into the dome, but leaving sufficient material between the holes for installing the screw stays. The feed-water may be introduced at any convenient place in the boiler shell below the water-line, usually at the coolest section of the boiler. This boiler is of the semi-portable type that may be moved about on skids, and then mounted on a brick founda-

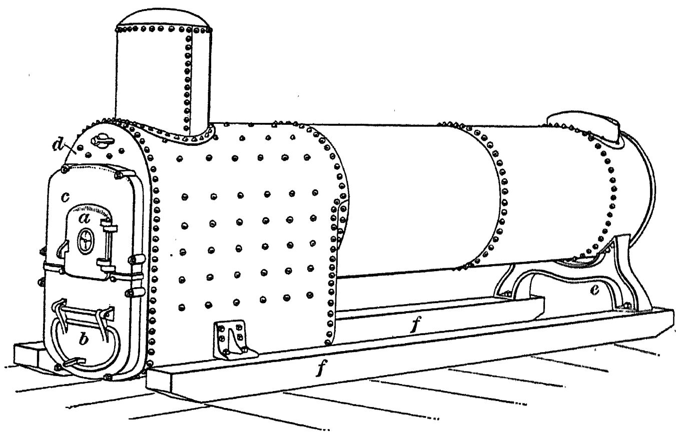


Fig. 15

tion x. In the operation of stationary boilers, with the exception of locomotive-type boilers, it is customary to speak of the end at which the firing is done as the front end. In the case of locomotive boilers the smokebox end is called the front end, since it is the forward end of a locomotive.

29. Wet-Bottom Firebox Type.—A perspective view of a semi-portable boiler of the firebox type is shown in Fig. 15. The bottom of the firebox, instead of opening into an ash-pit, is closed by a continuation of the water legs, and hence the furnace is entirely surrounded by water. A boiler thus constructed is said to be *wet-bottomed*. In the particular design shown, the

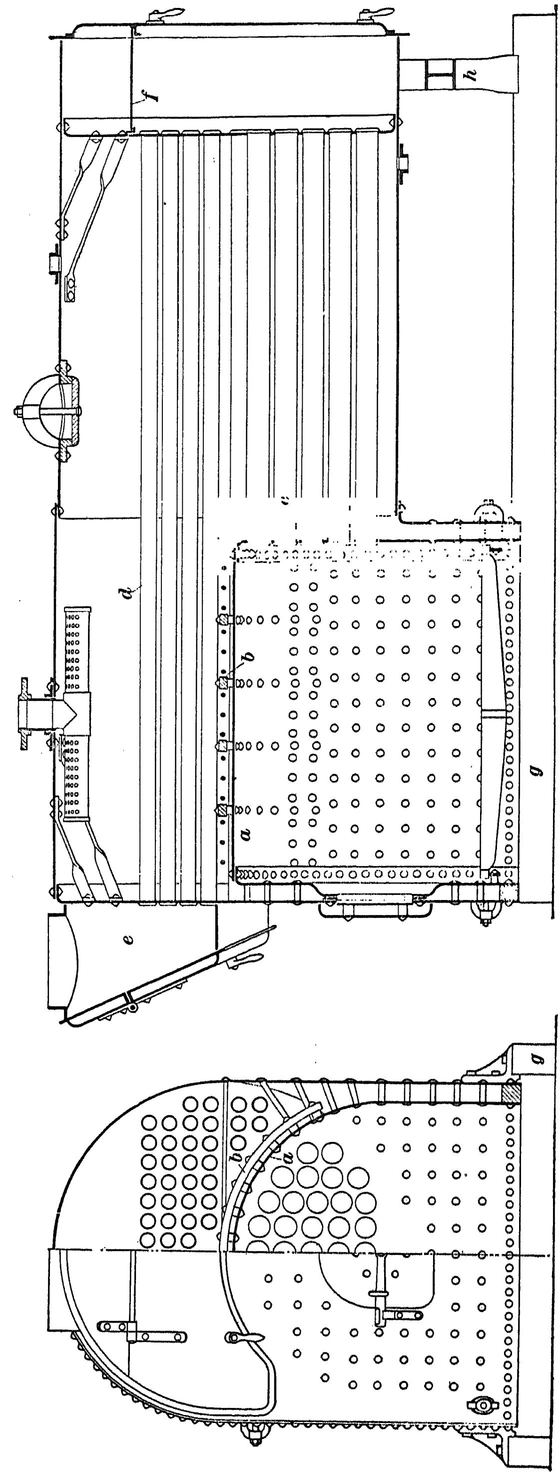


FIG. 16

fire-door *a* and ash-pit door *b* are attached to a cast-iron front *c* which, in turn, is bolted to the back head *d*; with this construction the firebox wrapper sheet is riveted directly to flanges formed on the back head, there being no furnace end or door sheet. The cylindrical part of the boiler is supported by a cast-iron cradle *e*. For convenience of shipment, the boiler is mounted on skids *f*, which may also serve as a temporary foundation. Some wet-bottom boilers have an ash-pit door in the center of the bottom instead of in the back head.

30. Pennsylvania Boiler.—In Fig. 16 is shown a form of boiler that is a combination of a firebox and a return-tubular boiler, and which is known as the Pennsylvania boiler. The firebox, or furnace, has a semicircular crown sheet *a*, which is stayed by solid crown bars *b* having a rectangular cross-section. The water legs are stayed by screw stays, as in locomotive boilers. The gases of combustion pass through the large, short, lower tubes *c* to a combustion chamber forming an extension of the cylindrical part of the boiler, and then return through the small, long tubes *d* to the smokebox *e*, whence they discharge into the chimney. A baffle plate *f* is fitted to the combustion chamber to prevent the hot gases from coming into contact with the upper part of the tube-sheet, which part is not covered by water.

The boiler is self-contained; that is, it requires no elaborate setting. It has the advantage over the locomotive boiler of having a much greater depth of water over the crown sheet, and the heated gases have a longer tube travel, thus making it possible to use a greater amount of the heat from the products of combustion. For convenience in shipment, the boiler is mounted on skids *g*, the cylindrical part of the boiler being supported in a cast-iron cradle *h*, which is utilized when the boiler is set permanently on a foundation.

HORIZONTAL WATER-TUBE BOILERS

31. Advantages of Water-Tube Boilers.—The boilers previously described have been of the types in which the water surrounds the tube or tubes, the flame and hot gases being inside the tube. In the water-tube boiler this condition is reversed; the water is inside the tubes, which are surrounded by the fire and hot gases. Water-tube boilers are commonly known as safety boilers, because an accident to any one tube or fitting does not necessarily involve the destruction of the whole boiler. They are extensively used for both land and marine service. The demand for very high steam pressure has led to the development of the water-tube boiler.

32. It is maintained that the heating surface in water-tube boilers is much more effective than an equivalent area of surface in the ordinary tubular boilers. In water-tube boilers, the direction of the circulation is well defined and there are no interfering currents. The circulation is rapid and over the entire boiler, keeping it at a nearly constant temperature and tending to deposit all the sediment at the lowest point. The water is divided into small bodies, the boilers steam quickly, and are sensitive to slight changes of pressure or condition of the fire. The arrangement of a water-tube boiler is such as to form a flexible construction, any member being free to expand without unduly expanding any other member. This very important feature tends to prolong the life of the boiler.

There is considerable difference in the amount of soot collected in a fire-tube and on a water tube. Soot accumulates within a fire-tube, and it may become filled, while the water tube holds the soot only on the top surface. Water-tube boilers are of sectional construction, and hence may be transported and erected more readily than other types.

33. Babcock and Wilcox Boilers.—The Babcock and Wilcox boiler is built in two classes, namely, the longitudinal-drum type and the cross-drum type. These types are made with vertical or inclined tube headers, which are formed in pressed steel or are iron castings, depending on the working

G07 6111

N28.25

pressure for which the boiler is constructed. The longitudinal drum is standard, although, where head room is a factor, the cross-drum type is built to meet the requirements.

In Fig. 17 are illustrated the details of construction of the longitudinal-drum Babcock and Wilcox boiler. It consists of one or more horizontal drums *a*, dependent on the size of the

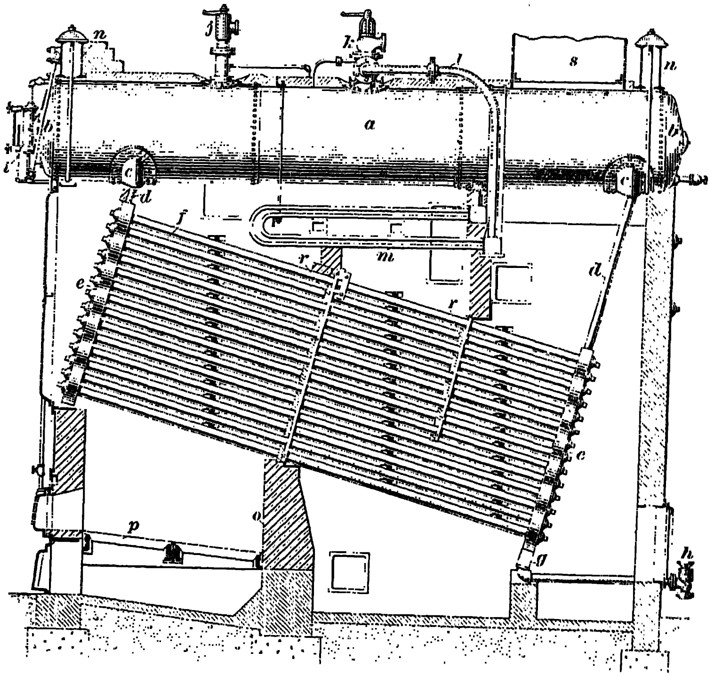


FIG. 17

boiler and its capacity, usually made of three cylindrical courses riveted together with single-riveted seams. These particular seams are called *girth seams,* or *circumferential seams.* The riveted joints running lengthwise of the drum are called *longitudinal seams.* They are made by butting the longitudinal edges of the drum sections together and covering the joints with outside and inside plates, which are riveted together with the shell plate. Joints made in this way are called *butt joints.* The heads *b* close the ends of the drum.

34. The drum heads are pressed to the form shown in Fig. 18, with a manhole opening *a*. The flange of the manhole acts as a stiffening ring and provides additional strength to the plate around the opening. The stiffening ring is faced off to form a seat for the manhole cover-plate. Flat raised seats are also pressed in the head at *b* for the water column and at *c* for the feedwater connection. Cross-tube boxes *c*, Fig. 17, are riveted to the drum of the boiler. These tube boxes are pressed to the form shown in Fig. 19 and shaped so as to fit snugly to the curvature of the drum. Tube holes are bored in the bottom face of the box, for the attachment of the tubes *d*, Fig. 17, that connect the tube headers *e* and the drum *a*, thus providing the means for circulation of steam and water in the front and rear tube headers. The tube headers *e* are curved along the sides, being so shaped that adjoining header sections fit snugly together and permit a staggered arrangement of the water tubes. The sectional view, Fig. 20, shows the outline of the header section, with tube holes and handholes. The latter are placed directly opposite the tube holes and are of sufficient size to permit cleaning and renewal of the tubes. A section is shown of the handhole plate *a* and the crab *b*. The nut *c* is used in bringing the handhole plate *a* to its seat so as to form a steam-tight joint.

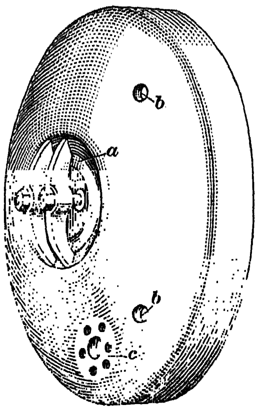


FIG. 18

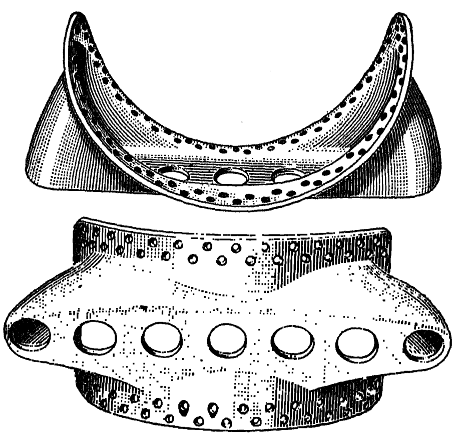


FIG. 19

35. The *mud-drum* g, Fig. 17, to which the header e is connected, is a steel box $7\frac{1}{4}$ inches square, and of sufficient length to connect the tube-header sections. It collects mud and sediment that settle at the bottom of the vessel. The sediment is removed through handhole openings in the drum or is blown out through the blow-off connection h. The pressure gauge and the water column i are connected to the drum a. A safety valve j is attached to the drum and another safety valve k is connected to the main steam pipe l that leads from the superheater m.

The superheater is constructed of pipe coils and headers through which the steam from the steam space of the drum a is circulated. The superheater is set directly in the furnace, and is subjected to the hot gases. If at any time no steam should be drawn from the boiler, the superheater would become overheated. The safety valve k is provided to prevent this condition. It is set at a pressure slightly below that of the safety valve j, and when the pressure rises it will open and permit some steam to flow through the superheater.

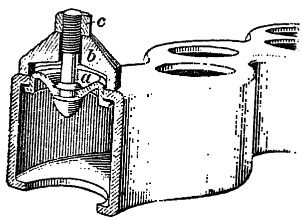


FIG. 20

36. Feedwater is introduced through the front drum head b, Fig. 17, and is carried back to the rear of the drum. It flows downwards in the rear header e, then through the tubes f to the front header e, and upwards through this header to the drum a. The water that is not transformed into steam again follows the circulation. The steam that is liberated in the drum a is stored in the steam space and is drawn off either through a dry pipe or through the superheater m.

The method of supporting the longitudinal-drum boiler shown is to suspend the rear and front ends from steel **I** beams n, which rest on columns, thus forming a structural frame support independent of the brickwork in the setting. This method allows for expansion and contraction without affecting the boiler or setting. This type of boiler, in common with most boilers

of the water-tube type, requires a brick setting to form the furnace and combustion chambers. The boiler furnace is built in the setting at the front of the boiler under the tubes. At the bottom of the furnace, extending up to the tubes, is built a bridge wall *o*, which forms a support for the grates *p*. The bridge wall prevents the gases and flame from traveling directly back to the rear of the boiler. By means of the walls *r*, built in between the tubes, and commonly called *baffles*, or *baffle walls*, the products of combustion are compelled to travel in a zigzag path around the tubes to the smoke outlet *s*, thus increasing considerably the gas travel in the boiler furnace.

37. Boilers of the cross-drum type are constructed similarly to the longitudinal-drum type. The main difference is in the arrangement of the upper drum, which is placed above and across the rear header. Horizontal circulating tubes are used to connect the drum and the front header to provide means for the circulation of water and steam. Vertical tubes connect the drum and the rear tube header.

38. Heine Water-Tube Boiler.—A boiler differing in many respects from that shown in Fig. 17 is the Heine boiler, illustrated in Fig. 21. It consists of a large main drum *a*, above and parallel to the nests of tubes *b*. Both drum and tubes are inclined to the horizontal at an angle that brings the water level to about one-third the height of the drum in front and to about two-thirds the height in the rear. The ends of the tubes are expanded into the large wrought-iron water legs *c*. These legs are flanged and riveted to the shell, which is cut out for about one-fourth of its circumference to receive them, the opening being from 60 to 90 per cent. of the cross-sectional area of the tubes. The drum heads form segments of a sphere, and therefore do not need bracing. The water legs form the natural support of the boiler, the front water leg being placed on a pair of cast-iron columns *d* that form part of the boiler front, while the rear water legs rest on rollers, shown at *e*, that can move on a cast-iron plate embedded in the rear wall. These rollers allow the boiler to expand freely when heated.

39. The Heine boiler is enclosed by a brickwork setting in the usual manner. The bridge wall *f*, Fig. 21, made largely of firebrick, is hollow, and has openings in the rear to allow air to pass into the chamber *g* and mix with the furnace gases. In the rear wall is the arched opening *h*, which is closed by a door and further protected by a thin wall of firebrick. When it is necessary to enter the chamber *g*, the wall at *h* may be removed and afterwards replaced. The feedwater is brought

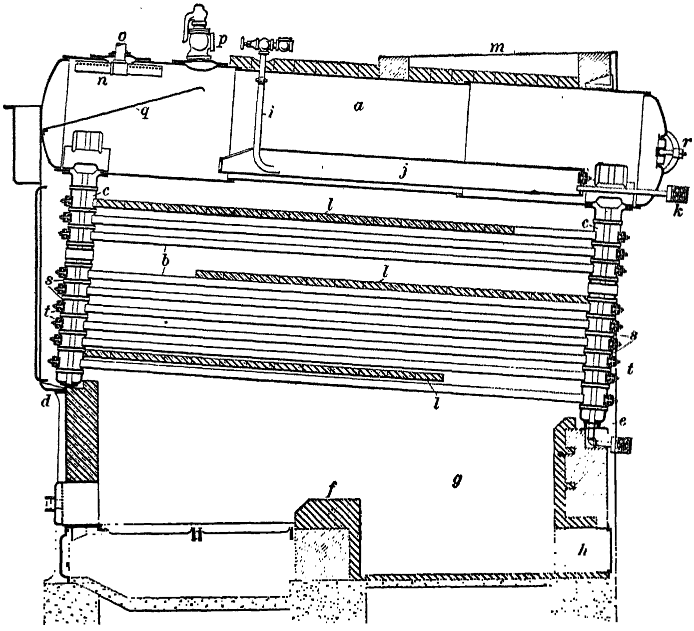


FIG. 21

in through the feedpipe *i*, which passes through the top of the drum. As the water enters, it flows into the mud-drum *j*, which is suspended in the main drum below the water-line and is thus completely submerged in the hottest water in the boiler. This high temperature is useful in causing the impurities contained in the feedwater to settle in the mud-drum *j*, from which they may be blown out through the blow-off pipe *k*. The water passes back out of the open end of the mud-drum and circulates in the same direction as in the boiler shown in Fig. 17.

40. Layers of firebrick *l*, Fig. 21, are laid at intervals along the rows of tubes and act as baffle plates, forcing the furnace gases to pass back and forth over the tubes. The gases finally escape through the chimney *m* placed above the rear end of the boiler. To protect the steam space of the drum from the action of the hot gases, the drum in the vicinity of the chimney is protected by firebrick, as shown. The steam is collected and freed from water by the perforated dry pipe *n*. The

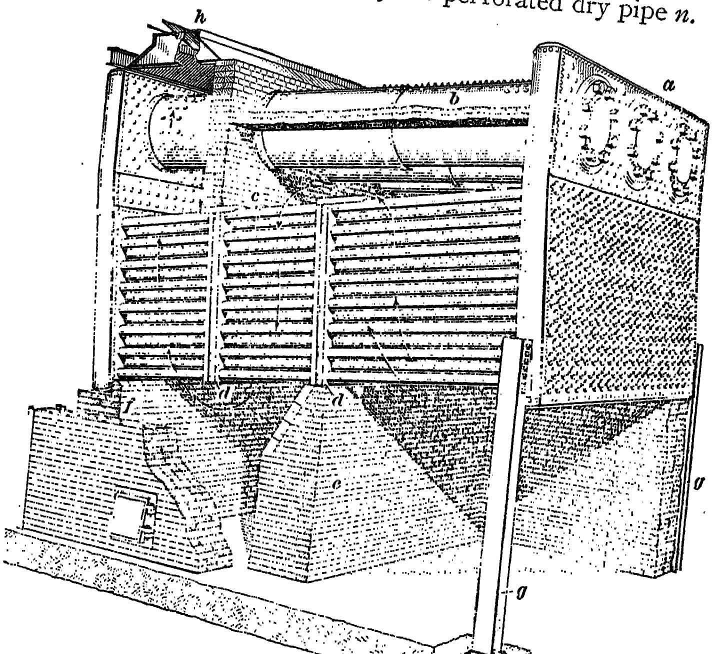


Fig. 22

main steam pipe is attached at *o*, and the safety valve is shown at *p*. In order to prevent a spray of mixed water and steam from spurting up from the front header and entering the dry pipe, a deflecting plate *q* is placed in the front end of the drum. A manhole *r* is placed in the rear head of the drum. The flat sides of the water legs are stayed together by the staybolts *s*, which are made hollow to permit a small steam pipe to be inserted, forming a blower to clean soot from the outside of the

tubes. In front of each tube a handhole t is placed to give access to the interior of the tube. When a group, or battery, of several boilers is used, additional steam drums are placed parallel to the drums a.

41. Edge Moor Water-Tube Boiler.—The Edge Moor water-tube boiler, shown in Fig. 22, is also made up of tubes, tube headers, and drums. The distance feature in its construction is the tube header a, which is carried above the

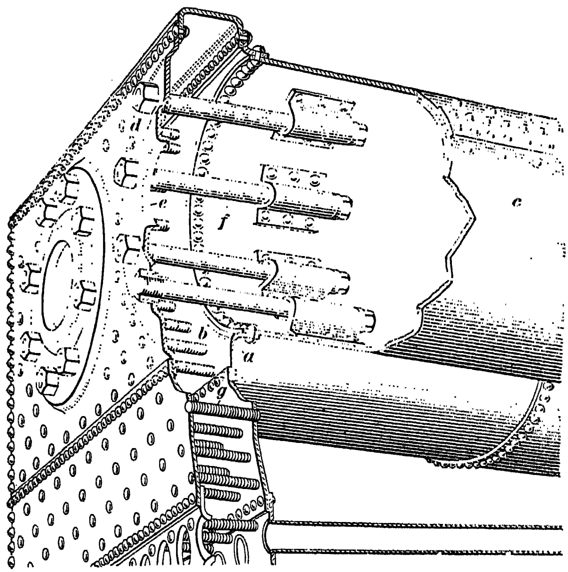


FIG. 23

drums b, thus providing additional steam and water space. The section, Fig. 23, shows the tube-header details and how the drum is arranged and stayed to the header connection. A flange a is turned on the header plate b, into which the drum c is set and riveted. To reinforce the outer sheet d around the manhole opening e, the stays f are installed. All flat plates of the headers are stayed with screw staybolts g, which are screwed into the inner and outer sheets and riveted over. Opposite each tube is placed an elliptical handhole. The hand-

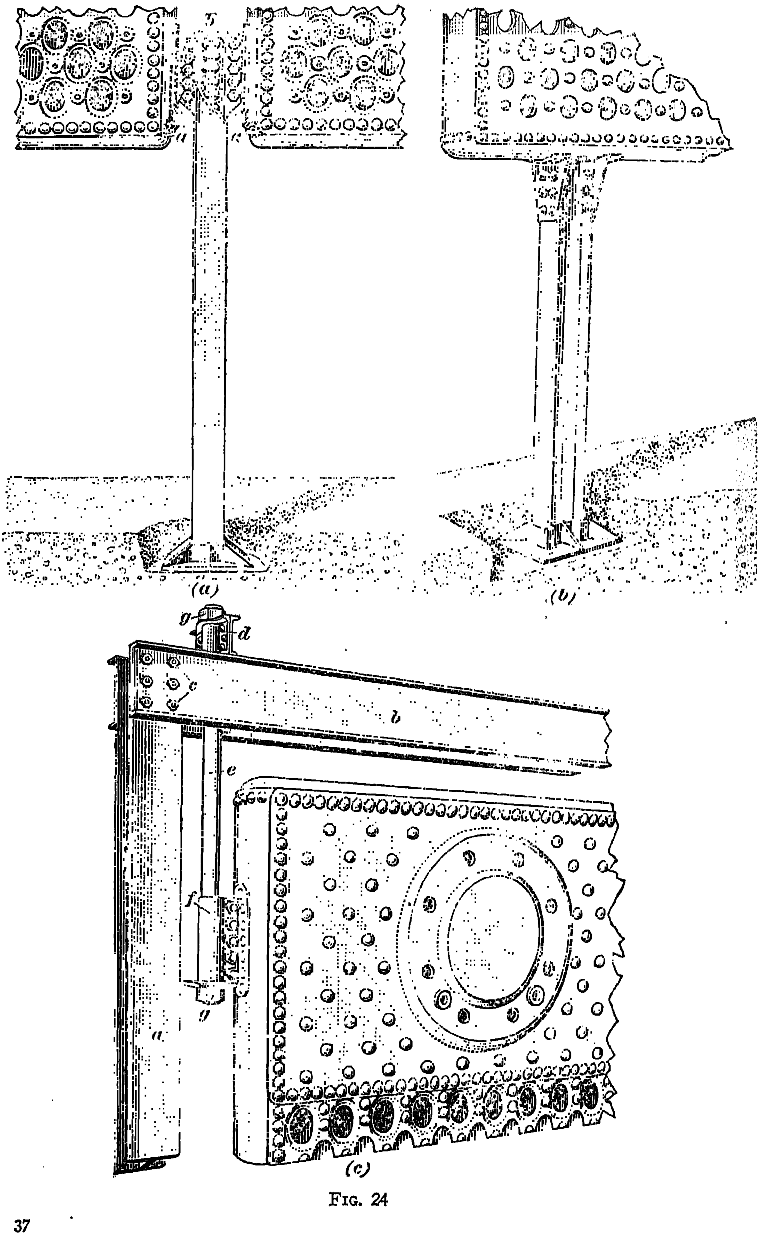


Fig. 24

hole plates are removable through their own openings; and through these openings the tubes are cleaned or repaired. Fig. 22 shows the relative arrangement of the tube headers *a*, drums *b*, tubes *c*, baffles *d*, and bridge wall *e*, and a section of the boiler setting *f* with the front structural supports *g*. The grates and other details are not shown. The grate sections would be placed in front of the bridge wall, under the high end of the boiler. The fuel gases travel in the direction of the arrows, upwards around the front tube section, downwards about the middle tube section, and upwards around the rear tube section to the smoke breeching *h*.

42. The Edge Moor boiler is supported by columns or suspended from overhead beams. Column supports for the headers are shown in Fig. 24 (*a*) and (*b*). View (*a*) shows an **H** column used for supporting the front of a battery of boilers. It is placed between the headers and bolted to angle clips *a* that are fastened to the headers. Angles *b* are riveted to the web of the **H** column. A foundation plate *c* is embedded in the concrete floor that forms a base for the column. The saddle support, view (*b*), is placed at the rear of the boilers, under the back headers. The suspension method of supporting the boilers is illustrated in view (*c*). Either **H** or **I** beams *a* form the column supports, and channels *b* form the cross-beams. The channels are bolted together at each end by bolts *c*, and spacers or sleeves are placed between the backs of the channels, through which the bolts pass. The spacers keep the channels apart and in alinement. A special steel sleeve *d* rests on the channels. A hanger bolt *e* passes through the sleeves *d* and *f*, and an adjusting nut *g* facilitates adjusting the boiler so that the headers hang plumb with the supports.

VERTICAL WATER-TUBE BOILERS

43. Bigelow-Hornsby Water-Tube Boiler.—The difference between the Bigelow-Hornsby boiler and those already described is in the tube arrangement and the shape of the tube headers. A typical installation, represented in Fig. 25, is com-

posed of a steam and water drum *a*, connected to the tube headers *b* by circulating pipes *c*. The headers *b* are cylindrical and the upper head *d* of each header is flanged and riveted to the shell. A standard manhole opening, 11 inches by 15 inches, is flanged in each head. The bottom heads in the lower tube head-

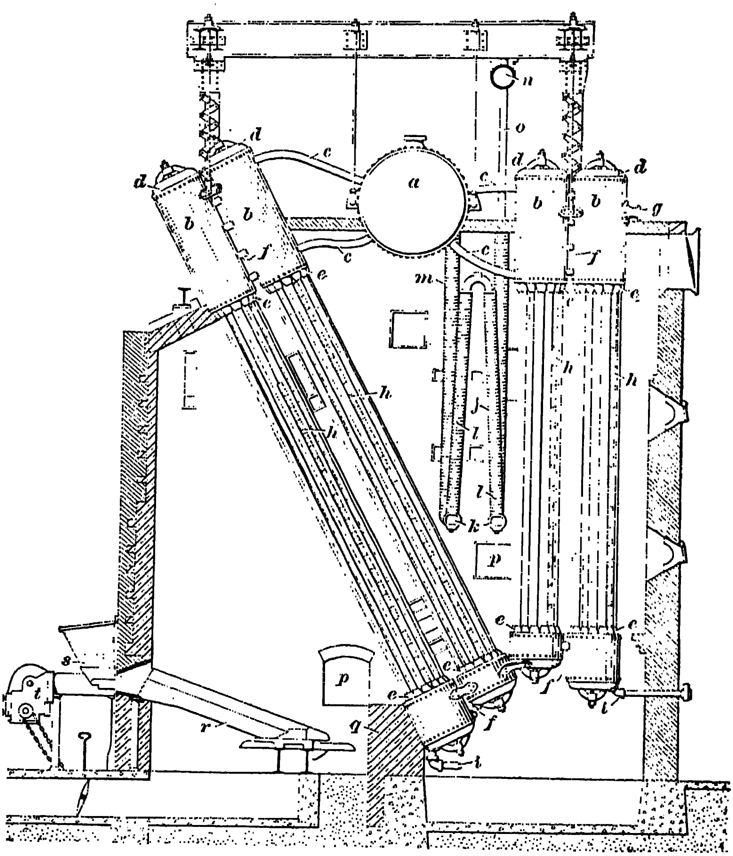


FIG. 25

ers are made in the same way, and standard manholes permit access to the drums to inspect, clean, and repair the tubes or header plate. The manholes eliminate the use of handhole plates. Tube plates *e* are shaped by a hydraulic press and dies to form suitable seats for the tubes. Each nest of tube headers

is connected to the adjoining set by circulating tubes *f*, giving the required means for circulation of steam and water. A nest of 21 tubes directly connects the upper and lower tube headers.

Feedwater enters the top rear header through the connection *g*, passes down the rear tubes, and is then carried by the circulation up the tubes in the front tube units. It thus passes through the rear tube units, which are in contact with the cooler gases of combustion, before entering the forward units where the heating surfaces are directly in contact with the fire and hottest gases. Baffle plates *h* are placed between the tubes to change the gas travel.

44. The lower drum headers, Fig. 25, collect the mud and other sediment that settles when the water is heated to a high temperature. Bottom blow-off connections *i* are installed in the lowest part of the drum heads for the purpose of blowing out mud and sediment. Beneath the main drum *a* is shown a superheater *j* made of pipe bent to a **U** shape, with the legs connecting headers *k*. To protect the wrought pipes or tubes from the corroding effect of the gases, cast-iron cover-plates *l*, called grids, are fixed around the superheating tubes. Steam is drawn from the drum *a*, passes down the pipe *m*, and circulates through the **U** tubes of the superheater to the main steam piping *n*, which is connected to the superheater by the pipe *o*.

Owing to the length of the drum and tube-header units, the setting must have high headroom. The tube-header units are suspended from structural members installed outside the boiler setting. Suitable clean-out and inspection doors *p* are provided for the convenient removal of refuse that collects back of the bridge wall *q*, and for the inspection of the boiler sections, which must be made periodically. The furnace in this installation is constructed for firing the fuel with a mechanical device *r*, called a *stoker*. The coal hopper is shown at *s* and the propelling machinery at *t*. The grates of the stoker are inclined.

45. Stirling Water-Tube Boiler.—A well-known type of bent-tube stationary boiler is the Stirling water-tube boiler, shown in Fig. 26. It consists of a lower drum *a* connected with three upper drums *b* by three sets of nearly vertical tubes *c*.

The upper drums are connected by the curved tubes *d*. The curved forms of the different sets of tubes allow the different parts of the boiler to expand and contract freely without strain. The boiler is enclosed in a brickwork setting, which is provided with various openings *e*, so that the interior may be inspected or repaired. The boiler is suspended from a framework of wrought-iron girders, not shown. The bridge wall *f* is faced

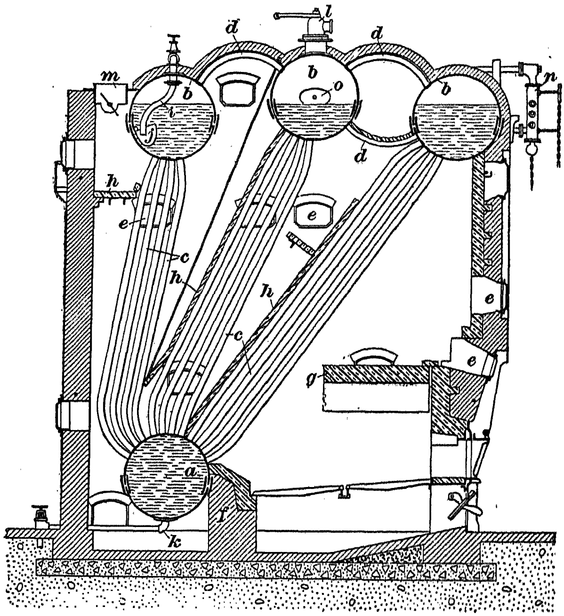


Fig. 26

with firebrick, and is built in contact with the lower drum *a* and the front nest of tubes. A firebrick arch *g* is built above the furnace, and this, in connection with the brick baffles *h*, directs the course of the heated gases, causing them to pass up and down between the tubes. The arch *g* becomes heated to a white heat, promoting combustion, and heating the incoming air when the furnace doors are opened, thus protecting the boiler from being chilled when the fires are being cleaned or stoked.

46. The feedwater enters the rear upper drum through the pipe *i*, Fig. 26, passes into the trough *j*, and descends through the

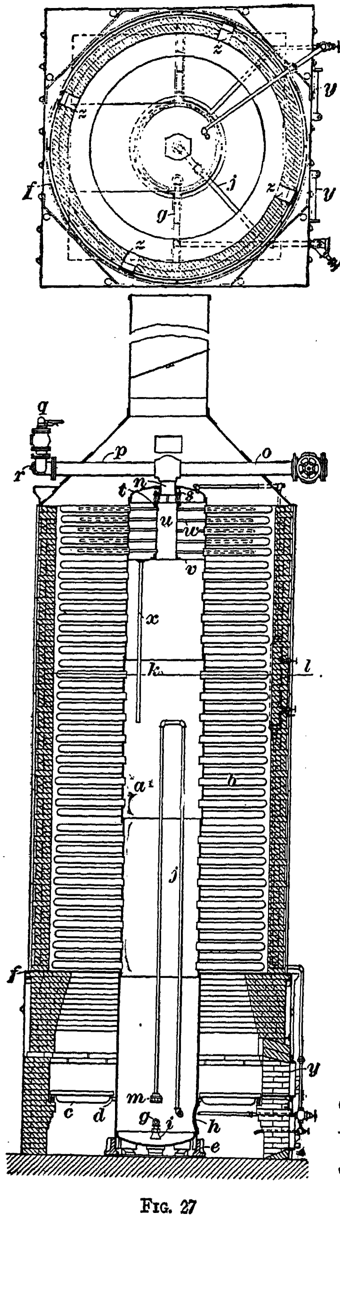


FIG. 27

rear nest of tubes to the drum *a*, which acts as a mud-drum and collects the sediment from the water. From the drum *a* the water passes upwards through the two forward sets of tubes and is vaporized as it rises, the steam passing from the front drum to the middle drum through the upper set of curved tubes *d*, while the unvaporized water circulates between the front and middle drums through the lowest set of curved tubes *d*, and thus the heated water does not again mingle with the comparatively cold water in the drum *a*. The steam collects in the upper drums *b*. A blow-off pipe *k* permits the removal of the sediment. The steam pipe and the safety valve *l* are attached to the middle drum. The chimney connection *m* is located behind the rear upper drum. The water column *n*, with its fittings, is placed in communication with the front upper drum. Each drum is provided with a large manhole *o*.

47. Hazelton Water-Tube Boiler.—The Hazelton boiler, sometimes called the *porcupine boiler*, because of the rather peculiar arrangement of the water tubes, is shown in Fig. 27. It consists of a vertical shell *a*, to which a large number of radial

tubes *b* are attached, having their inner ends expanded in the tube holes in the shell and their outer ends closed. The grates *c* surround the cylinder near the bottom. The inner ends of the grate bars rest on a ring *d* supported by brackets riveted to the shell, and the outer ends rest on a plate on the brickwork enclosing the ash-pit. The boiler rests on a circular cast-iron base *e* placed on a masonry foundation. The boiler and furnace are enclosed in brickwork that supports the chimney. The brickwork is built up square to the height of the lower tubes and circular above that point. The furnace brickwork is encased in sheets of steel riveted to angle irons at the corners and reinforced by angle and **T** bars riveted to the casing. An air space is provided between the brick lining and the casing to decrease the radiation.

48. The top of the furnace wall, Fig. 27, supports a circular steel plate *f*, on which is built the brick setting above the furnace. The circular brick setting is enclosed in sections of sheet steel bolted together. The firebrick lining of the furnace is built so as to slope inwards at the top and deflect the flame against the standpipe of the boiler. The lower end of the standpipe below the grates forms a settling chamber, or mud-drum. It is fitted with a blow-off pipe *g* and a manhole *h* opposite one of the ash-pit doors. The blow-off pipe enters the mud-drum below the grate and terminates in a cone-shaped nozzle *i*. The feed-pipe *j* enters the shell below the grate and extends vertically nearly to the water-line *k l* in the boiler. It then passes downwards and delivers the water through a spraying nozzle *m* at the level of the grate.

49. The steam outlet is through a heavy nipple *n*, Fig. 27, screwed through the center of the top head of the steam drum. A **T** on the outer end of the nipple provides openings for the steam pipe *o* and a pipe *p* leading to the safety valve *q*, but this arrangement is not to be recommended; for, when the safety valve blows, the rush of steam to the outlet may cause water to be drawn along with the steam to the engine or turbine, and may result in a wrecked cylinder or stripped turbine blades. It is good practice to keep the steam outlet and the safety-valve outlet separate and as far apart as possible. A handhole *r* is

located on the end of the pipe below the safety valve, which is uncovered to afford ventilation to the interior of the boiler when it is necessary for a man to enter it. The nipple *n* terminates at its lower end in a flange *s*, to which is bolted a blank flange *t* at a distance of several inches. This blank flange closes the top of a short length of large pipe *u* suspended from it.

50. A diaphragm plate *v*, Fig. 27, is attached to the lower end of the pipe *u* and the shell of the boiler and closes the annular space between them. From the central pipe *u* a large number of small pipes *w* radiate horizontally and extend into the boiler tubes nearly to their outer ends. The steam flows from the central pipe through the small pipes into the boiler tubes, and thence backwards into the top of the steam drum, whence it passes out between the two flanges *s* and *t*. A drip pipe *x* is suspended from the diaphragm and extends a short distance below the water level in the boiler. Two firing doors *y* are located at one side of the furnace, and several doors are conveniently located in the brick setting, so that an examination can be made of the exterior of the boiler shell and tubes.

51. Wickes Water-Tube Boiler.—Another form of vertical water-tube boiler, known as the Wickes boiler, is shown in Fig. 28. It consists of two cylindrical drums *a* and *b* joined together by a number of long straight tubes *c*. The tubes are separated by a baffle plate *d* of firebrick, passing through the center of the tube nest, thus dividing the tubes into two banks. The boiler drums are of the same diameter, but differ in height and in the arrangement of the convex heads *e*. The upper, or steam, drum *a* is closed at the bottom with a tube-sheet *f*. The drum *b*, which is the water drum and mud-drum, is much shorter than the steam drum, and its top is closed by a tube-sheet *g*. At the bottom of the mud-drum, a blow-off pipe connection is made at *h* for the removal of mud and sediment. The arrangement of the manholes *i* in both the upper and lower drums permits entering the boiler at its highest and lowest points for inspection, for repairing of the tubes, and for cleaning purposes, as required in the removal of scale from the drums and boiler tubes.

The feedwater enters the steam drum *a* through a pipe *j* located at the back of the boiler, farthest from the furnace, and flows directly down through the rear tubes, called *downcomers,* to the water drum. The circulation is continued up the *risers,* or tubes, in front of the baffle wall *d*. A baffle plate is arranged

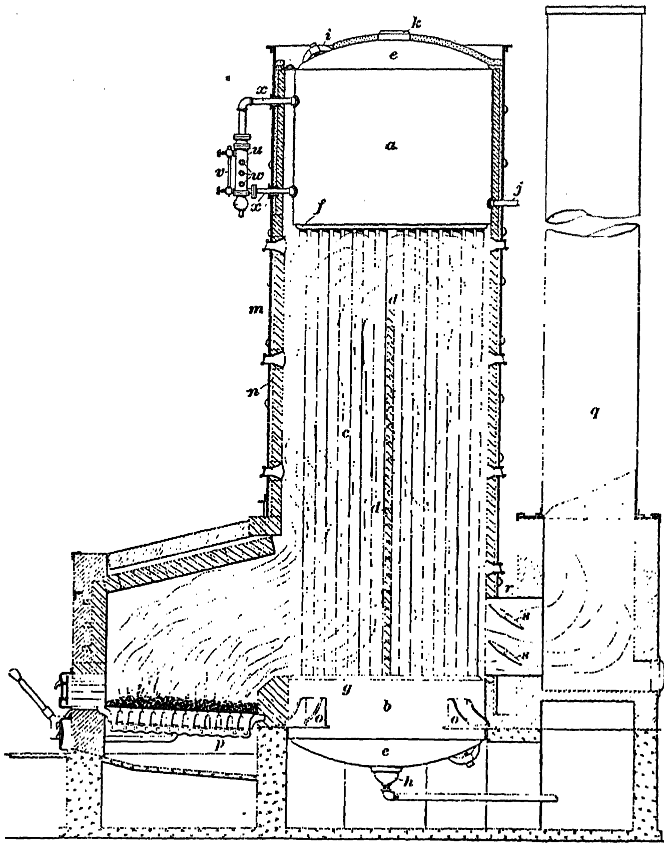


FIG. 28

on a level with the water-line in the steam drum *a,* directly over the risers. By it the water that rises with the circulation is deflected to the section above the downcomers, and thus particles of water are prevented from escaping with the steam that passes out the main steam outlet *k*.

52. The brick setting around the boiler in Fig. 28 is independent of the boiler installation. By this arrangement, the boiler is free to expand and contract without affecting the walls of the setting. The brick wall is surrounded by a steel jacket *m*, and non-conducting material *n*, such as asbestos or magnesia, is placed between the jacket *m* and the brick wall. The boiler is supported by brackets *o* that are riveted to the mud-drum and that rest on a foundation placed under the boiler. Incorporated with the setting are the furnace and grates *p*, so arranged outside of the boiler that the heat and flames have a long travel around the boiler tubes. The flow of the heated gases is produced by the draft of the chimney *q*. They flow around the first bank of tubes in front of the baffle *d*, over the baffle, down about the downcomer tubes, through the breeching *r*, and to the stack. A double swinging damper *s* is installed in the breeching between the stack and the boiler setting, to control the draft or flow of gases. A clean-out door *t* is placed back of the stack, in the setting, so that entrance is made for cleaning, inspection, and repairs to the stack connection. Boiler accessories, such as the water column *u*, with the gauge glass *v* and the gauge-cocks *w*, are attached to the steam drum *a* by the piping *x*. The upper pipe *x* is in communication with the steam space above the highest water-line and the lower is attached below the water level.

53. Cahall Boiler.—The Cahall boiler, shown in Fig. 29, consists of a cylindrical mud-drum *a* and steam drum *b*, which are connected by nearly vertical tubes *c* that form a tube nest having an open space in the center in the form of an inverted cone. In this space are installed deflecting plates *d*, or baffles. The furnace *e* is placed to one side of the boiler, and the gases of combustion surround the tubes, being deflected by the baffles *d* to a sweep nearly at right angles to the tubes. They finally pass out through a central passage in the steam drum to the smokestack. The steam becomes slightly superheated in this steam drum, through coming in contact with the surface of the central passage, which is kept at a fairly high temperature by the escaping gases. The steam drum and mud-drum are connected by an external circulating pipe *f* that enters the steam drum

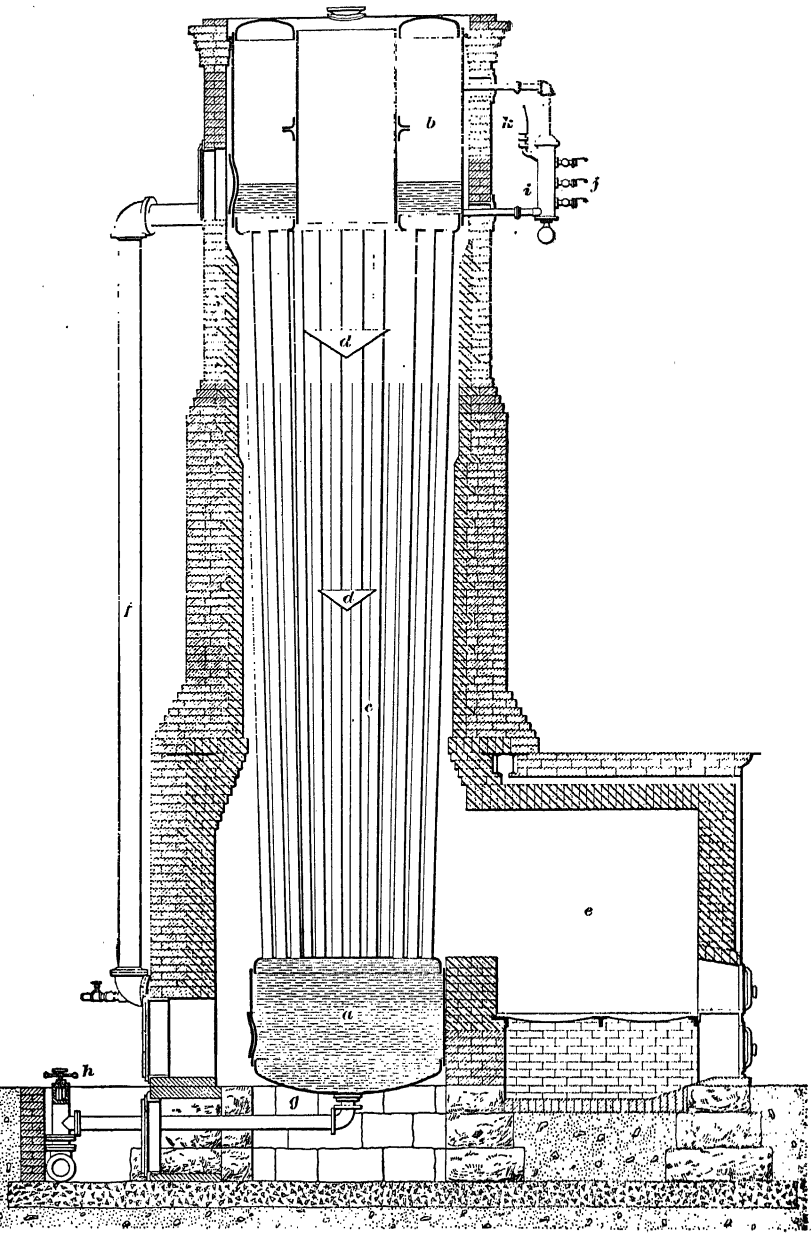


Fig. 29

some distance below the water-line. The feedwater enters the mud-drum and, becoming highly heated, rises through the vertical tubes to the steam drum, where the steam bubbles are liberated.

Some of the water in the lower part of the steam drum flows continually into the circulating pipe, and since this pipe is not exposed to the heat of the fire, the density of the water in it is much greater than the density of the water in the vertical boiler tubes. In consequence, the water is continually flowing downwards and a rapid circulation is promoted. The blow-off pipe *g* is connected to the bottom of the mud-drum, and the blow-off valve *h* is arranged on the outside of the boiler setting. The water column *i*, the gauge-cocks *j*, and the water glass are attached to the drum *b* for determining the water level. A whistle *k* is incorporated with the water column, its purpose being to give an alarm when the water level falls too low in the boiler.

MARINE BOILERS

CLASSIFICATION

54. Steam boilers for marine service are made in a great variety of forms, but there are at least four well-defined types, as follows: Scotch, locomotive, tubular, and water-tube boilers. Each branch of marine service demands a boiler adapted particularly to its requirements. For example, the Scotch boiler is used in freighters and large, slow-moving passenger steamships; the locomotive and tubular types are used in small vessels; and the water-tube types are mainly used in high-speed passenger, freight, and war vessels.

FIRE-TUBE MARINE BOILERS

55. Scotch Boilers.—The Scotch boiler is distinctively a marine boiler. It is of the fire-tube type and is internally fired, the number of internal furnaces varying from one to four,

according to the size of the boiler; but three is a very usual number. The diameter of the furnace ranges from 24 to 48 inches. Boilers under 9 feet in diameter have one furnace; those from 9 to $13\frac{1}{2}$ feet in diameter have two; those from $13\frac{1}{2}$ to 15 feet in diameter have three; and those beyond 15 feet in diameter have four. Large furnaces are preferable as they permit a greater inclination of the grates, thus assisting in the efficient combustion of the fuel and producing better economy. The thickness of the shell plates of the largest Scotch boilers is $1\frac{1}{2}$ inches.

The simplest Scotch boiler is of the single-ended type, having furnaces and tubes at one end only, and fired at only one end. This type of boiler is made in sizes up to 18 feet in diameter and 12 feet in length. In the early form, the furnaces opened into one common combustion chamber, which made it difficult to operate the boiler economically. In the present type, each furnace and its combustion chamber are independent of the other furnaces and their combustion chambers, with water surrounding each section.

56. Single-Ended Scotch Boiler.—An end view of a single-ended Scotch boiler is shown in Fig. 30 and a longitudinal section in Fig. 31. The boiler consists of a cylindrical shell *a*, which is made in one or two sections, depending on the length of the boiler. The furnaces *b* are corrugated and of the *horse-collar* type, taking this name from the shape of the collar, or flange connection, by which the furnace is riveted to the rear tube plate *c*. Circular collars or flanges may be used, but the advantage of the horse-collar type is that the furnace can be removed through the circular opening in the front end in case repairs are required. Each corrugated furnace opens into a combustion chamber *d*, and the adjoining combustion chambers are stayed together by screw stays *e*. A nest of fire-tubes *f* extends from the front tube plate to the rear tube plate and the tube ends are expanded in the tube holes and then beaded over. The tubes *g*, of heavier metal, called *stay tubes,* are threaded and screwed into the tube plates, thus forming stays that support the tube plates.

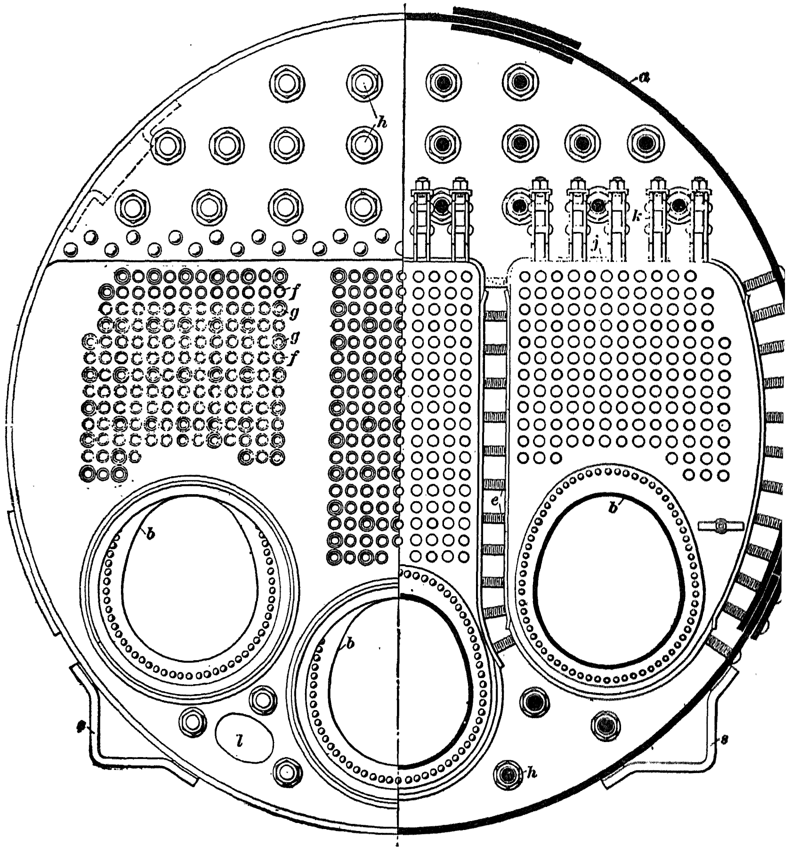


Fig. 30

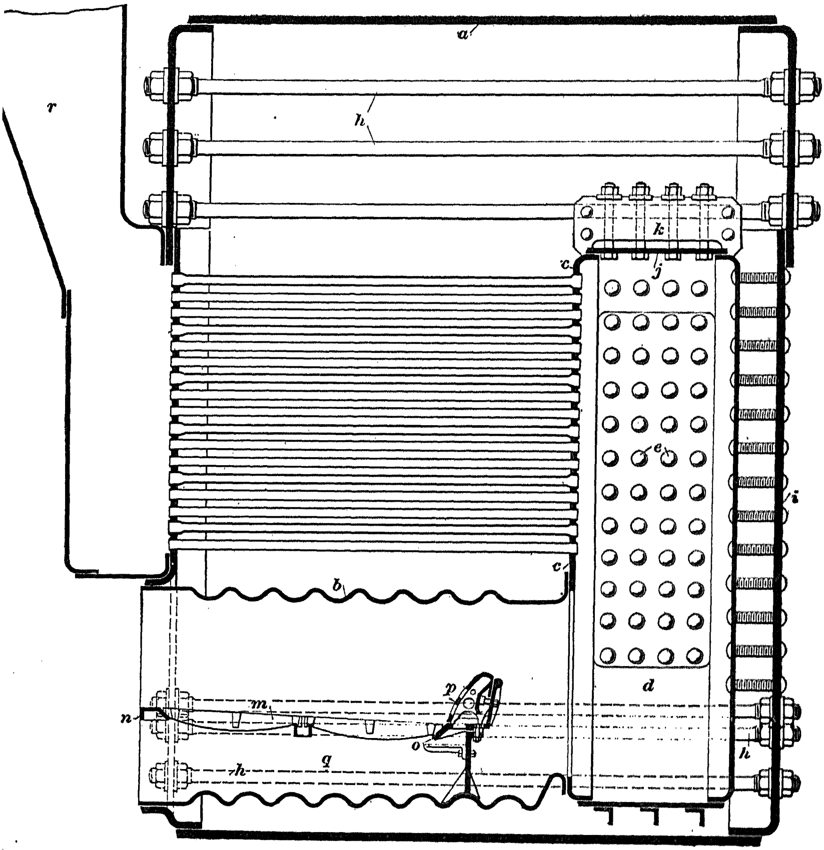


FIG. 31

1
I L T 459—5

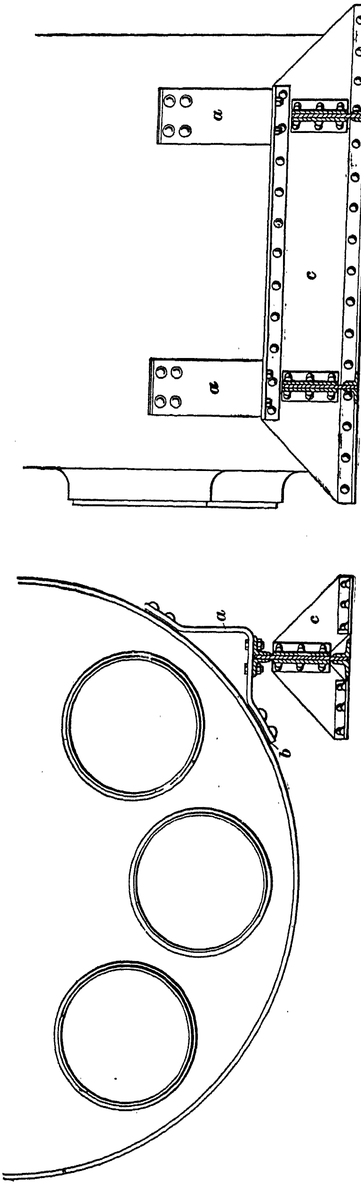


FIG. 32

57. Owing to the size of the boiler heads, they are usually made in two or three sections and riveted together. The flat sections of the rear and front heads are supported by large end-to-end stays *h*, Figs. 30 and 31, which are fitted with inside and outside nuts and washers. The sides of the outer combustion chambers are stayed to the shell plate, and the rear plates of these chambers to the back head *i*. The crown sheets *j* are supported by steel girder stays, or *crown bars*, *k*. The manholes *l* give access to the boiler for inspection and cleaning the various boiler parts. Furnace details, such as the grate bars *m* and dead plates *n*, are placed within the corrugated flues *b*. It is necessary to make the grates long in order to provide the necessary grate area. A cast-iron plate *o* supports the rear ends of the grate bars and also carries the sectional bridge wall *p*, which is made up of a series of cast-iron sections set side by side across the furnace. Slots between adjacent sections admit air from the ash-pit into the current of gases passing

over the top of the bridge wall and thus improve the combustion. Below the grates is the ash-pit *q*. The gases arising from the combustion of the coal pass into the combustion chamber *d*, where they are more thoroughly mixed with air and consumed. They then pass through the tubes to the breeching *r*. The material used in the heads is flange steel of ductile quality, and the tubes are made of the best charcoal iron or of seamless drawn steel tubes, both of which under good operating conditions give equally satisfactory results.

58. The Scotch boiler is supported by saddle plates *s*, Fig. 30, details of their construction being shown in Fig. 32. The lug *a* is of heavy steel, bent to shape and riveted to the shell of the boiler. Each lug has a calking strip *b*, made of $\frac{1}{4}$-inch plate, between it and the shell. Girders *c* are fastened to the framing of the ship, and to these the lugs *a* are bolted, provision being made at one end for freedom of movement to accommodate expansion and contraction. To promote economical operation, the bottom of the boiler is covered with *lagging*, made of asbestos or magnesia, that prevents cooling by the circulation of air along the bottom.

59. The diagrammatic views given in Fig. 33 (*a*) and (*b*) show the direction of circulation of the water in the Scotch boiler. The water directly above the tops of the furnaces *a* becomes heated and rises among the tubes *b* as well as between the nests of tubes. The cooler water above descends to take the place of the water that rises, and it travels along the shell, outside the outer nests of tubes, as well as between the rising streams between the tube nests. The directions of these various currents are indicated by the arrows.

At the bottom of the boiler, below the furnaces, as at *c*, the movement of the water is very sluggish, because the water in that space is not in contact with effective heating surface; also. there is some conflict between the rising and descending currents, to retard the circulation. As such inequality of temperature in different parts of a boiler sets up stresses in the plates and seams, devices for creating circulation of the water are sometimes used. One method is to place a steam nozzle in the

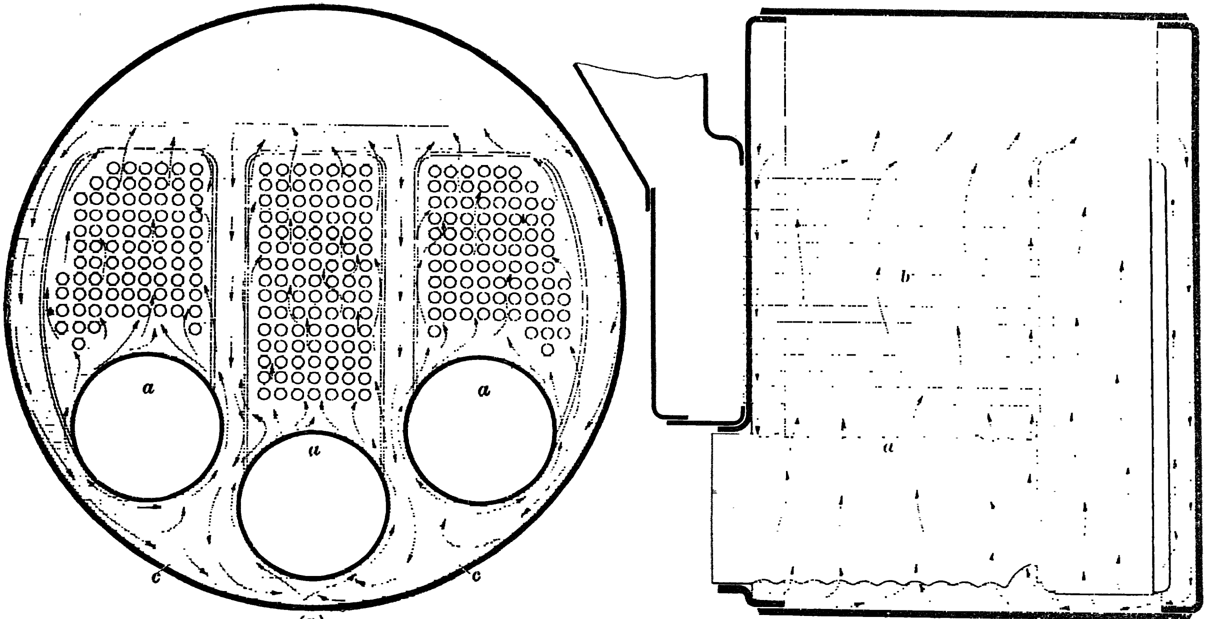


FIG. 33

water space near the bottom, and to use the escaping jet to induce a rapid circulation of the water, thus keeping all parts of the boiler at approximately the same temperature. The incoming feedwater also tends to set up a circulation of water in the boiler.

60. Double-Ended Scotch Boiler.—The double-ended Scotch boiler has furnaces at each end, and resembles two single-ended boilers placed back to back. It is lighter, cheaper, and occupies less space than two single-ended boilers. In double-ended Scotch boilers the furnace flues at each end com-

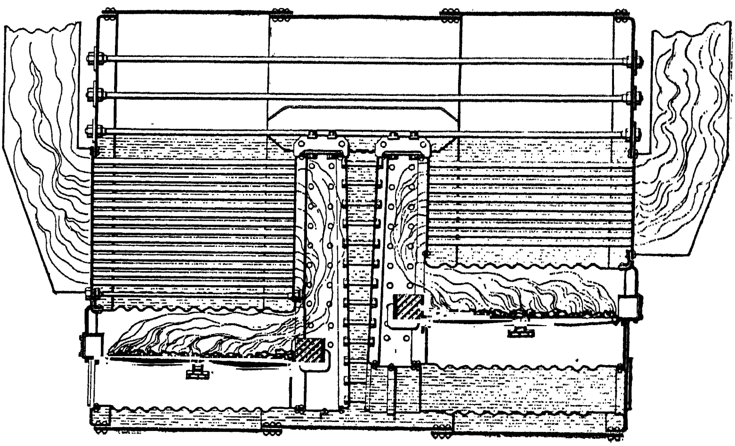


Fig. 34

municate with a centrally located combustion chamber, from which the products of combustion pass through fire-tubes, as in Fig. 34, leading to two smoke flues, one on each end. Sometimes the boiler is so arranged that each opposite pair of furnace flues opens into a common combustion chamber, as shown in Fig. 35. In such a case, each combustion chamber will have two nests of tubes, one nest connecting it with one head, the other nest with the other head. The gases from two opposite furnaces mix together in the common combustion chamber, and then pass through the two nests of tubes, one-half to one smoke flue, the other half to the other.

61. On account of the high steam pressures used in modern marine engines, the marine boiler must be carefully designed for strength. It is likewise necessary to reduce its weight and size to the lowest possible limits. The following data relating

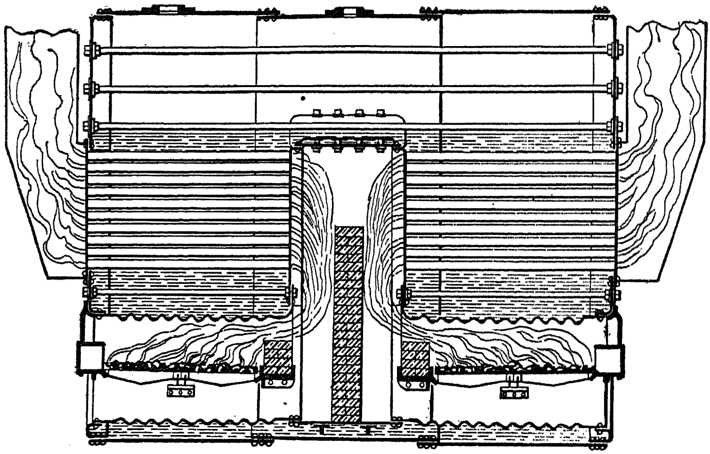


FIG. 35

to the boilers of a naval vessel will give an idea of the principal dimensions of a Scotch marine boiler made of Siemens-Martin steel.

Diameter of shell	15 ft. 2 in.
Length of shell	9 ft. 6 in.
Working pressure	135 lb. per sq. in.
Thickness of shell plates	$1\frac{5}{32}$ in.
Thickness of heads	$\frac{7}{8}$ in.
Number of furnace flues	4
Diameter of furnace flues	3 ft. 1 in.
Thickness of furnace flues	$\frac{15}{32}$ in.
Diameter of stayrods	$1\frac{15}{16}$ in.
Diameter of staybolts	$1\frac{1}{4}$ in.
Number of tubes	490
Diameter of tubes	$2\frac{1}{2}$ in.
Length of tubes	6 ft. 8 in.
Heating surface	2,500 sq. ft.
Weight without water	about 40 tons

For the sake of safety, the Scotch type of boiler must be made extremely heavy and bulky when high steam pressures

are used, and much attention is being paid to devising a type of boiler that, while retaining the good features of the Scotch type, will be lighter, smaller, and cheaper for the same power.

62. Advantages of Scotch Boiler.—The Scotch boiler is durable under rough usage, and is easy to operate and repair. The tubes are straight and standard in size, making it possible to obtain new tubes in almost any seaport. Leaky tubes can be plugged without reducing pressure on the boiler. As the tubes are straight, they are accessible for cleaning and repairing without removing boiler connections. The number of pounds of water evaporated per pound of fuel burned has proved satisfactory. It is internally fired and therefore eliminates the air leakage that arises in built-up settings. The disadvantages of this type are: excessive weight, poor circulation in the body of water below the effective heating surfaces; loss of time in starting boilers for operation; and time required to blow off and cool the boiler down for repairs.

GUNBOAT BOILERS

63. Locomotive Type for Marine Purposes.—In some gunboats and other small naval vessels, there is not sufficient room under the decks for the large Scotch boilers, and the type of boiler shown in Fig. 36, resembling the locomotive boiler, is frequently used. It is a plain cylindrical boiler with two rectangular fireboxes *a* (only one of which is shown), each connected by a nest of fire-tubes *b* to the rear boiler head. The furnaces are large, so as to leave sufficient space for combustion over the fires. Handholes *c* and *d* are located in the front head; and on top of the shell, near the rear end, is a manhole *c* that affords ready access to the interior of the boiler for inspection, cleaning, or repairs.

64. Tubular Type.—A modification of the Scotch boiler, made for the purpose of providing a boiler of small diameter that can be placed where headroom is very limited, is the gunboat boiler shown in Fig. 37. The peculiarity of this boiler is that the tubes, instead of being placed above and around the

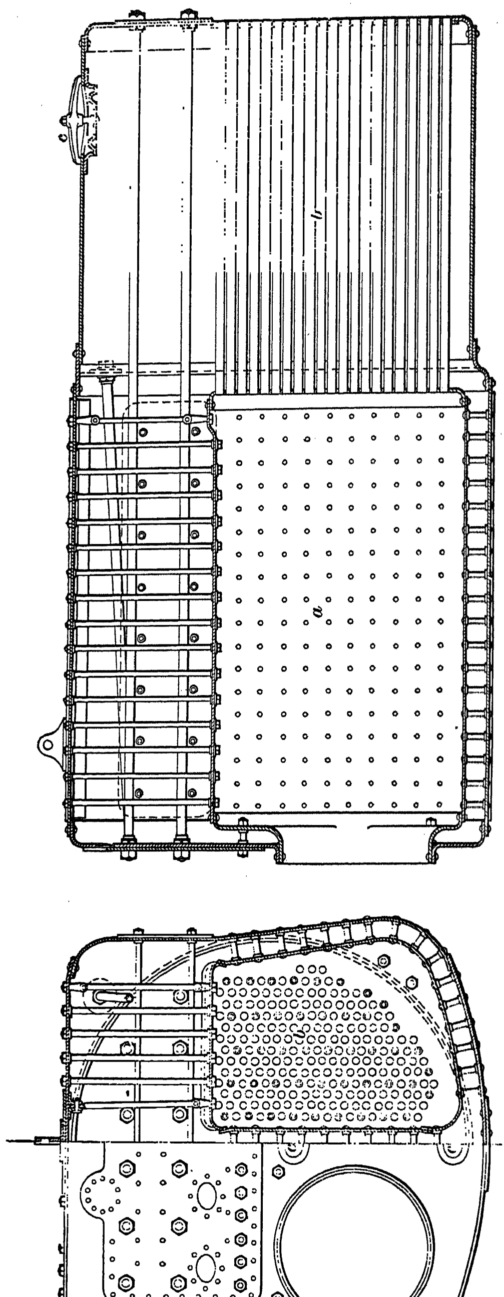


Fig. 36

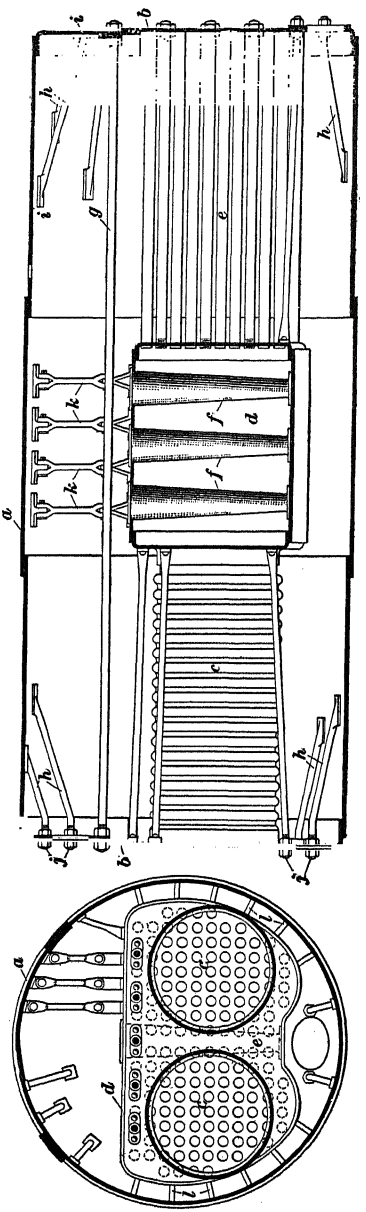


FIG. 37

furnace flues, are placed in in the rear and in line with them. By this arrangement of the parts, the boiler is greatly reduced in diameter, but its length is doubled. The reduced diameter enables the shell to be made of thinner plates. This boiler consists of a cylindrical shell *a* with flat heads *b*. The corrugated furnace flues *c* are similar to those used in the ordinary Scotch boiler, and, as usual, contain the grates.

65. The combustion chamber *d*, Fig. 37, is made twice the depth of the combustion chamber of a Scotch boiler of the same capacity, to compensate for its reduced height. The tubes *e* extend from the rear wall of the combustion chamber to the rear head of the boiler. The uptake or smokebox (not shown in the illustration) leading to the smokestack is attached to the rear head of the boiler. The combustion chamber is provided with the vertical tapering tubes *f*. These connect the upper and lower parts of the water space, promote circulation, add

considerably to the heating surface, and assist in staying and strengthening the flat top of the combustion chamber. They are made tapering to enable the flange at the lower or smaller end of the tube to be passed through the opening in the top sheet of the combustion chamber while the boiler is under construction. The tapering form, with the large end uppermost, also facilitates the release and discharge of the steam that is generated within the tubes, which are called *Galloway tubes.*

66. The heads of the boiler in Fig. 37 are braced by the tubes *e*, the furnace flues *c*, the longitudinal braces *g*, and the diagonal braces, or palm stays, *h*. The palm stays are made of round bar iron or steel forged with flat ends. In some cases, they have palms *i* at the ends, which are riveted to the shell and the head of the boiler; in other cases, they have a palm at one end only and are threaded at the other end. When they are made in this way, the palm end is riveted to the shell of the boiler and the threaded end passes through the head, with a nut on each side of the plate, as shown at *j*. The flat top of the combustion chamber is braced by the sling stays *k*. The sides and bottom of the combustion chamber are secured to the shell of the boiler by the staybolts *l*. The Clyde, or dry-back, boiler described in a preceding article is another boiler of the tubular type employed on small vessels.

WATER-TUBE MARINE BOILERS

67. Types of Water-Tube Marine Boilers.—The water-tube boilers in marine service resemble the water-tube boilers already described and possess the same advantages and disadvantages. Boilers of this type are classified as small-tube and large-tube; horizontal, vertical, and inclined; and as having straight tubes or bent tubes. The general custom is to designate marine water-tube boilers as either large-tube boilers or express boilers. Large-tube boilers, considered suitable for big ships, have tubes $1\frac{7}{8}$ inches or larger in diameter. Practically all boilers of this type have straight tubes. Express boilers are made of small tubes, from 1 to $1\frac{3}{8}$ inches in diameter.

These are closely spaced so as to obtain a high ratio of steam production to weight of boiler, which is necessary in small vessels of high speed, such as destroyers and torpedo boats. The tubes in this type may be straight or curved.

68. Features of Large-Tube and Small-Tube Boilers. Each of these types has its advantages and disadvantages, and it is a question as to which is the better. Large tubes require fewer joints for a given amount of heating surface, and they may be made thicker without decreasing materially their internal diameter. They contain a larger body of water than small tubes and so are not so liable to have all the water in them suddenly converted into steam under extreme forcing conditions, and thus leave the tubes exposed to overheating, as might occur in small tubes. Small-tube boilers generate steam more rapidly, and in case a tube is ruptured, less damage is likely to result than if a large tube should burst. Should it be necessary to plug a small tube, less heating surface will be made ineffective than in the case of the large tube.

69. Tube Arrangements.—Tubes in water-tube boilers are placed at all possible angles, from horizontal to vertical positions. The efficiency of the boiler and the ease of repairing and cleaning the tubes depend on the arrangement of the tubes. Horizontal tubes are liable to produce foaming, as the steam and water are delivered spasmodically, or in spurts, from both ends of the tubes when the boiler is forced. This condition may leave the tubes unprotected for a time and lead to overheating of the tubes. Scale and soot gather very readily on horizontal tubes, more so than on those that are vertical or are inclined at a considerable angle. Water does not circulate as freely through horizontal tubes as through inclined or vertical tubes, as the tendency of the heated water and steam to rise is resisted by the horizontal position and the small area of the tubes. As a result, the water and steam flow spasmodically.

Boilers having straight tubes properly arranged possess the advantage of being easily cleaned. Scaling tools can be passed through the tubes to remove the scale. Straight tubes can also be removed and replaced more readily than bent tubes. In

some bent-tube boilers it is necessary to remove sound tubes in order to replace a tube in one of the inner rows. Bent tubes permit a design that makes a lighter and more compact boiler than straight-tube types; hence, they are used for express boilers. Moreover, bent tubes are less liable than straight tubes to injury from expansion and contraction due to the severe operating conditions to which boilers of this type are subjected.

70. Belleville Water-Tube Boiler.—One form of large-tube boiler, known as the Belleville boiler, is shown in Fig. 38. It consists of a number of nearly horizontal tiers of water tubes *a*, screwed or expanded at each end into return bends *b*, making a series of zigzag inclined tubes, beginning at the top of the furnace door and ending at the steam drum *c*, which is located above the tubes. There is a handhole in each of the front bends or connecting boxes *b*. The mud-drum *d* stands vertically, and is located in front of the boiler and below the lowest tubes. The top of the mud-drum is connected to the bottom of the steam drum by a vertical pipe *e*. From the side of the mud-drum, a rectangular feedpipe *f* extends across the front of the boiler, joining each vertical tier of water tubes *a*. The mud-drum blow-off is at the center of the lower head.

71. The Belleville boiler is enclosed in a steel casing, as shown in Fig. 38. The fire-box is arranged below the tubes and runs their full length; the grate bars *g* slope downwards toward the rear. The products of combustion pass upwards between the tubes, thence about a superheater, and out near the top of the casing, as indicated by the arrows. Baffle plates *l* of steel or tile are fitted in the nest of tubes to deflect the hot gases, in order that the entire surface of the tubes may receive the benefit of the heat. The feedwater enters at one end of the steam drum and flows into a shallow pan *h*, then downwards through the external circulating pipe *e* to the mud-drum, and into the rectangular feedpipe *f*; thence it continues through the steam coils to the steam drum. The outlets of the water tubes in the steam drum are several inches above the bottom of the drum, so that the steam will not mingle with the comparatively cool water in the drum.

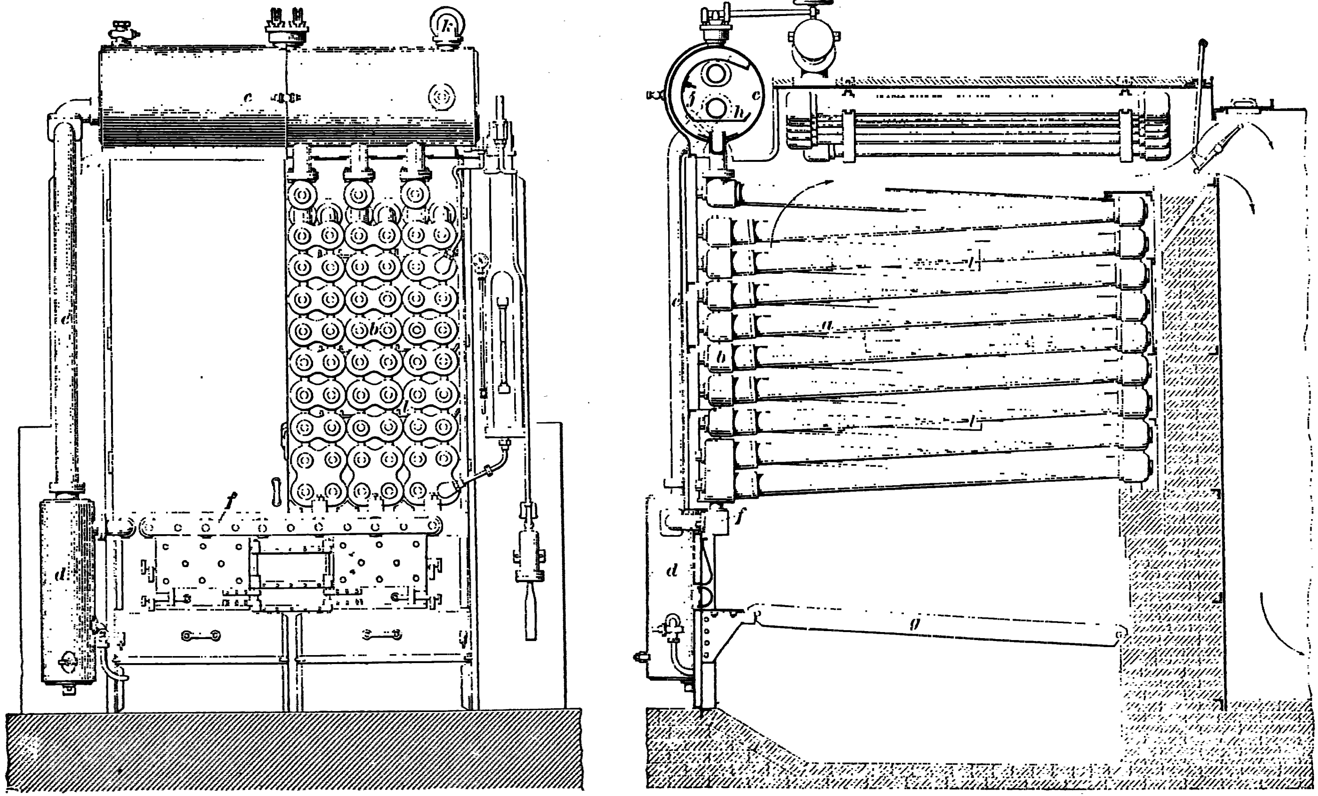


Fig. 38

72. The water passes into the mud-drum of the Belleville boiler through a non-return valve, and then to the bottom and up around a vertical baffle plate. The bottom of the drum forms a settling chamber, into which much of the sediment is deposited. The non-return valve keeps the water circulating in the same direction through the water tubes even when the ship is rolling. It also regulates the direction of flow when steam is being raised. The casing of the boiler is made of steel plates riveted together. Angle irons are used at the joints for stiffeners. The upper part of the casing is lined with magnesia and asbestos, and the lower part next to the fire with firebrick.

This kind of boiler has very little water capacity, and hence it is usually fitted with an automatic feedwater regulator. In operation, it requires very close attention. There is a strong upward flow of steam and hot water as they pass from the tubes into the steam drum. The pan *h*, Fig. 38, and its curved cover *j* serve as a deflector over the openings of the tubes to prevent the water from being carried out through the steam nozzle *k* on the top of the drum.

73. Babcock and Wilcox Marine Boiler.—The Babcock and Wilcox boiler of the mixed-tube type, built for either coal or oil burning, is one that meets the requirements of the British Admiralty, and is largely used in the United States in a variety of vessels. The dry weight of this boiler is much less than that of the Scotch boiler, averaging less than 20 pounds per square foot of heating surface as compared with 40 to 50 pounds per square foot for the Scotch boiler. The weight of water within the boiler ranges from 3 to 5 pounds per square foot of heating surface as compared with 17 to 20 in the Scotch type; hence, the space occupied by the Babcock and Wilcox marine boiler is considerably less than that occupied by the Scotch boiler of equal power.

The general features of construction, shown in Fig. 39 (*a*) and (*b*), are similar to those of the land boiler. The cross-drum *a* is placed at the front and is connected to the tube headers *b* by circulating tubes *c*. Each section of the front header *b*

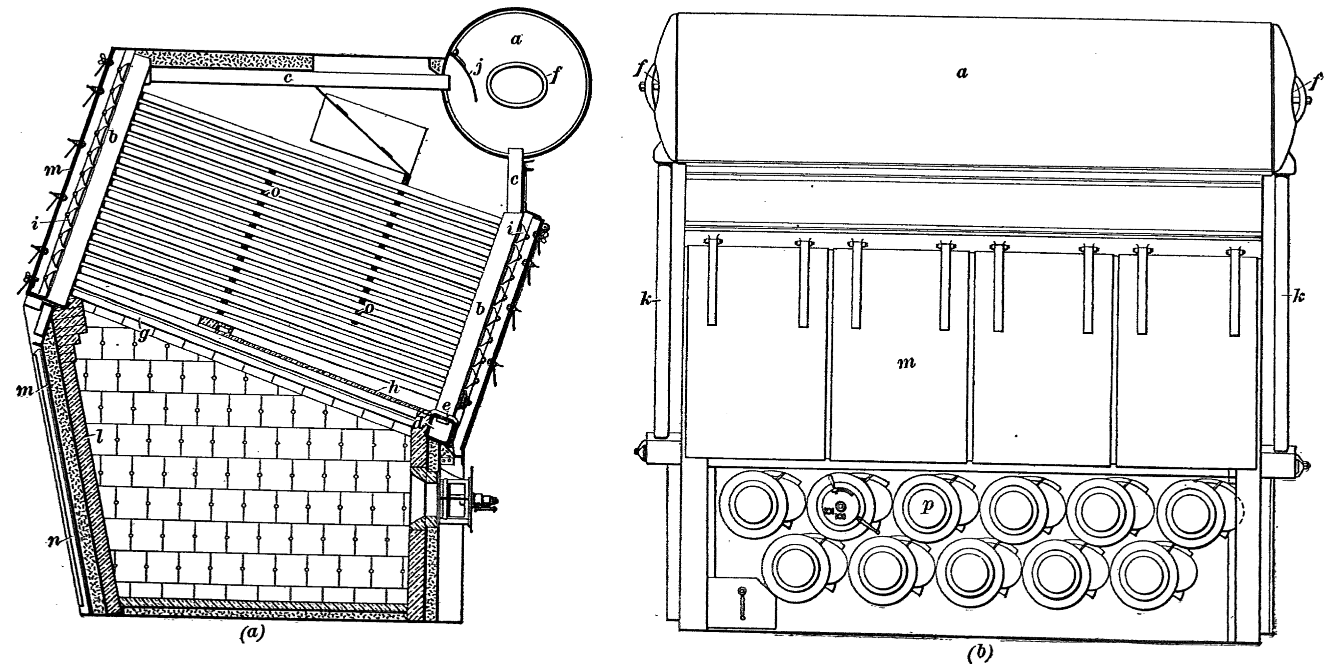


FIG. 39

is connected to the mud-drum *d*, by a short nipple *e*. At each end of the steam and water drum *a* is a manhole *f*. Directly over the furnace, in oil-burning boilers, the lower tubes *g* are inclined at an angle of 18° with the horizontal, while those above are inclined 15° with the horizontal. This difference in inclination leaves a space at the front of the boiler for the brick or tile baffle plate *h*.

74. As the tubes of the boiler in Fig. 39 are straight and accessible from each end, they are easily inspected and repaired. Handhole plates *i* are placed in the outside sheet of each tube header and opposite the tube openings. The circulation in the boiler is rapid and the steam produced is remarkably dry. Feed-water enters the drum *a*, descends through the front header, passes into the tubes, flows up through the back tube header, and through the horizontal tubes *c* into the steam and water drum *a*, striking the baffle plate *j*. The downcomers *k* also assist in promoting the circulation. These pipes connect the drum *a* and the mud-drum *d*. Mud and sediment are blown off through a blow-off valve and piping attached to the mud-drum. Handhole plates are fitted to each end of the mud-drum for cleaning and inspection purposes. The boiler furnace is encased in firebrick *l* and backed with a steel casing *m*, reinforced with angle irons *n*. The back tube header *b* is usually not covered, as boilers are usually set back to back, with a casing common to both, thus economizing room. Separate stack connections are made by installing uptakes leading from each boiler to the stack. Baffles *o* cause the gases to flow three times at right angles to the tubes. The boiler fittings, such as the steam gauge, water column, etc., are not shown. The devices *p* are oil-burning apparatus.

75. Babcock and Wilcox Box-Type Marine Boiler.—The distinctive feature in the construction of the Babcock and Wilcox box-type marine boiler, shown in Fig. 40 (*a*) and (*b*), is the arrangement of the steel headers *a* and *b*. They take the place of drums usually fitted in what is known as the **A** type of marine boiler, and are either of straight box form or of corrugated form. They run crosswise, as shown at *a*, or longitu-

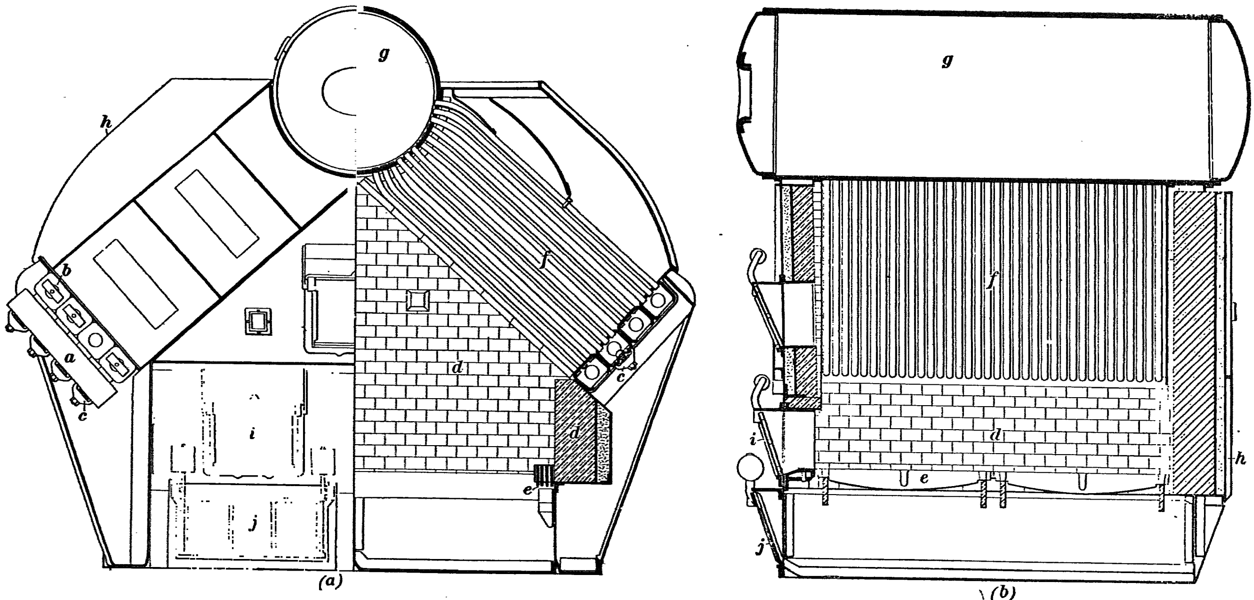


Fig. 40

I L T 459—6

dinally, as shown at *b*. Each header opposite a bank of tubes is so fitted with handhole plates *c* that examination, cleaning, and repair of the tubes may be made without interfering with other tubes. The view (*a*) is a conventional view of the boiler. The sectional drawing to the right of the vertical center line illustrates the interior arrangement of the combustion chamber and its side walls *d* and grates *e*. The tubes *f* are straight, except the end sections that join to the drum *g*, which are curved in order to have the tubes enter the drum at right angles to the contour of the shell. The view to the left of the center line indicates the details of the boiler covering, showing the steel casing *h*, fire-door *i*, and ash-pit door *j*. A lengthwise sectional elevation of the boiler is shown in view (*b*). Baffling of the gases is obtained by the use of baffle plates that are placed between the tubes and parallel to them.

76. Babcock and Wilcox Drum-Type Boiler.—In the Babcock and Wilcox cross-drum water-tube boiler, shown in Fig. 41 (*a*) and (*b*), the arrangement of the water drum *a* and steam drum *b* is such that the boiler is fired from the water-drum side. This type is an efficient design and can be operated with oil or coal as fuel. The water drum *a* is made in two sections; the lower section is semicircular and the upper part is made of heavier metal and is bent to a larger radius except at the corners, where the joint is made. This shape of the upper section permits a better arrangement and a larger number of tubes *c* in the boiler than would be possible if the section were made semicircular. At each end of the drums *a* and *b* is fitted an elliptical manhole plate *d*. The tubes *c* are bent at both ends, so that they will fit properly into the drum shells and have a good seat in the boiler plate. The bent sections have the advantage of yielding uniformly with the stresses set up by expansion and contraction. The gases are directed by baffles *e*, which are set perpendicular to the tubes, this arrangement causing the gases to make three passes around the tubes before they reach the smoke breeching *f*, which is brought forwards over the water drum *a*. The boiler setting *g* is arranged for oil burning, the oil burners being located at suitable open-

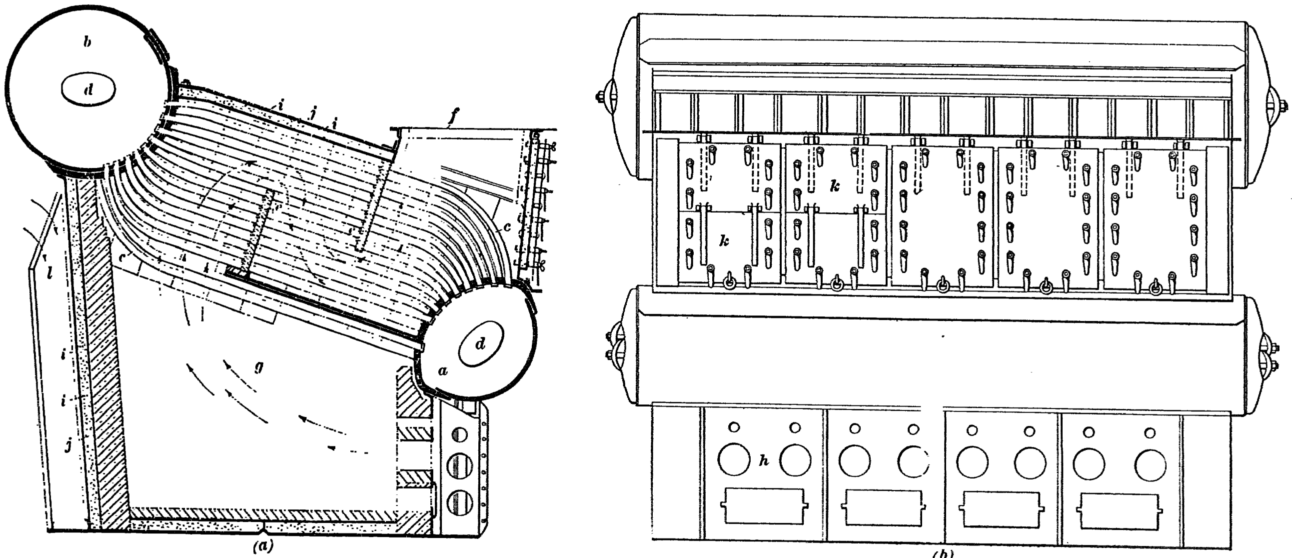


Fig. 41

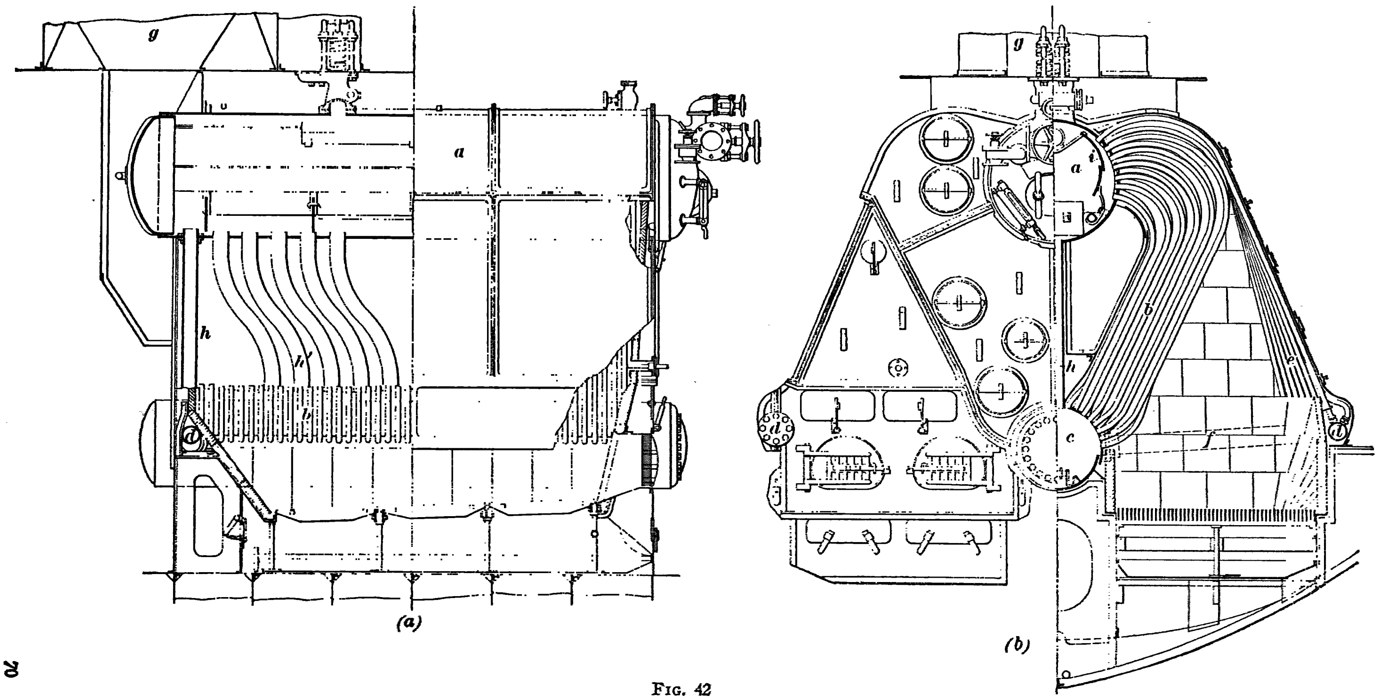


FIG. 42

ings in the boiler front, shown at *h*. The outer casing of the boiler is composed of an inner and an outer steel jacket, as shown at *i*, between which non-conducting material *j* is placed, such as asbestos, magnesia, and other mineral substances. Doors *k* are placed in the boiler casing in line with the tubes for boiler inspection and cleaning purposes. The duct *l* at the back of the boiler is for the purpose of admitting additional air to the furnace as needed for the combustion of fuel oil.

77. Thornycroft Water-Tube Boiler.—In Fig. 42 is shown the Daring type of Thornycroft boiler, a small boiler much used on boats of very high speed. It consists of a large horizontal steam drum *a* at the top, connected by a series of bent tubes *b* to a small central drum *c* located at the bottom, between the furnaces. There are also two smaller drums *d*, at the outside edges of the grates. These side drums are connected by rows of bent tubes *e* to the steam drum *a*, and by nearly horizontal pipe *f* to the lower central drum. There is a grate on each side of the central drum, and the products of combustion pass upwards between the tubes to the flue *g* at the front of the boiler. Inside the casing and near the front of the boiler are several large downcomers *h*, *h′*, joining the steam drum *a* to the lower water drum *c*. The feedwater enters the steam drum and descends through the vertical downcomer *h* to the lower drum, a portion passing to the small side drums *d*, thence up through the bent tubes *b* and *e*, where the mingled steam and water is delivered against a baffle plate *i* inside the upper drum.

The boiler setting is made of sheet-steel casing, lined with non-conducting material. Numerous doors are provided in the casing for cleaning and repairing the boiler. This type of boiler has been very highly developed and has proved very successful in torpedo-boat and torpedo-boat-destroyer service. Like all water-tube boilers, it holds very little water and is sensitive to slight changes in the condition of the fire.

78. Thornycroft-Schulz Water-Tube Boiler.—The Thornycroft-Schulz boiler, shown in Fig. 43, is a modification of the Daring boiler. It is superior to the latter in that it is more efficient in fuel consumption and evaporation. The main steam and

water drum *a* is connected to three lower drums. The bent tubes *b* connect the two outer drums *c* with the drum *a*, and the tubes are numerous, thus giving a large effective heating surface. The central drum *d* is connected to the drum *a* by bent tubes *e* and straight tubes *f* that form downcomers. Large downcomers *g* also connect the drums *a* and *c*, and assist very much in promoting rapid water and steam circulation. All of the tubes *e* and the downcomers *f* and *g* discharge into the steam drum below the water level, but only a few of the tubes *b* do this. As shown in view (*a*), most of the tubes *b* discharge directly into the steam space of the drum *a*. The tubes are formed to a large curvature and are therefore less liable to be damaged by expansion and contraction. The gases travel from the furnace in

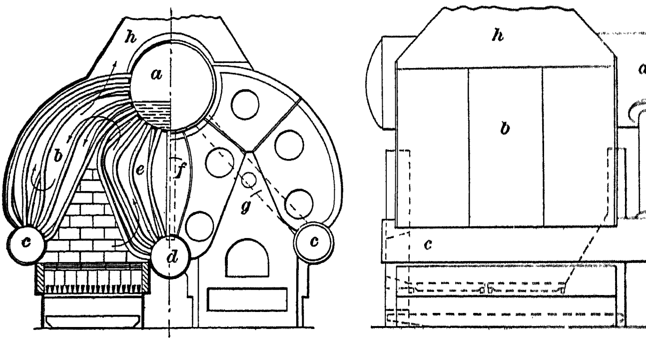


Fig. 43

the direction of the arrow and finally pass out through the breeching *h*. Baffle plates are installed between the tubes to cause the gases to travel as shown.

79. Modified Thornycroft Boiler With Superheater.—The distinctive feature of the modified Thornycroft boiler shown in Fig. 44 is the tube arrangement. View (*a*), to the left of the vertical center line, shows the interior of the boiler. The arrangement of the boiler front, superheater, and smoke breeching is illustrated to the right of the vertical center line. A rear view of the boiler is given in (*b*). The boiler is composed of an upper drum *a* and lower drums *b*, connected by the circulating tubes *c*. These tubes are straight, to the point where they

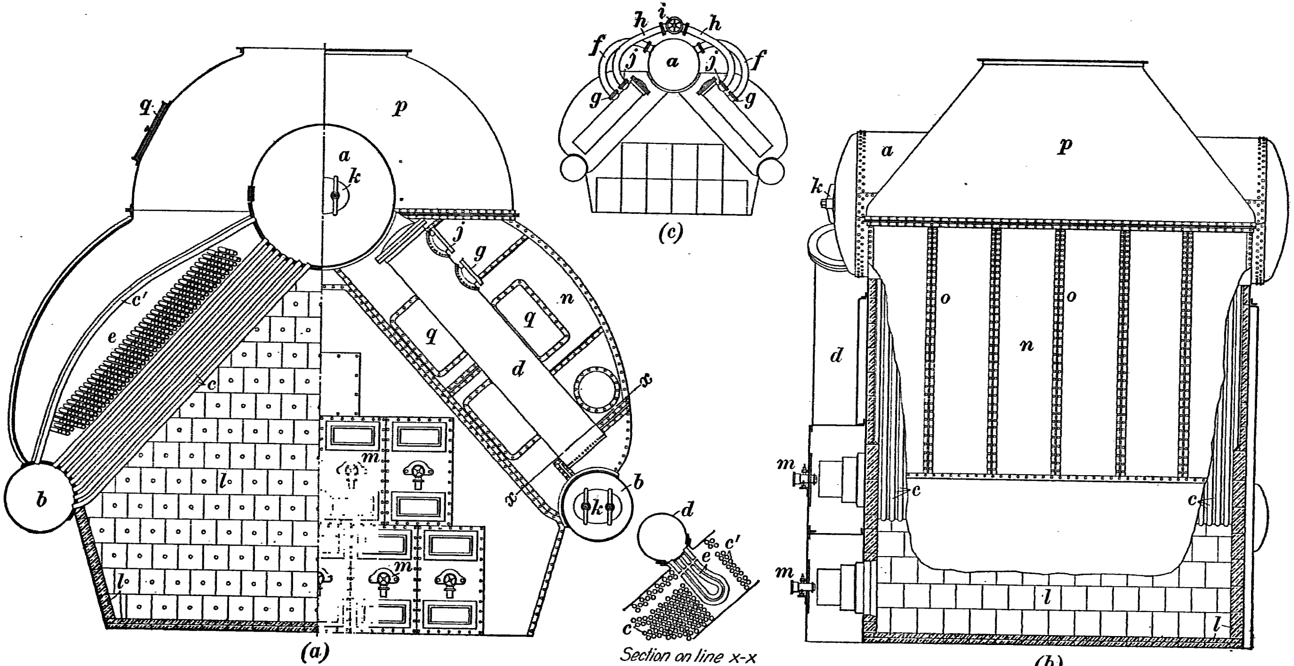

q
p
a
k
c'
e
c
l
b
j
g
n
q
d
x
m
h
i
f
g
(a)
(c)
d
c'
e
c
Section on line x-x
p
a
k
o
n
d
m
c
l
(b)

FIG. 44

join the lower drums *b*, at which point they are curved so as to fit properly into the holes in the drum. The outer rows of tubes *c′* are bent to a larger curvature and are used to baffle the gases as well as to increase the boiler heating surface. All of the tubes *c* and *c′* discharge into the water space of the upper drum.

80. The superheater drums *d*, Fig. 44, are placed outside of the boiler front, parallel with the boiler tubes. The sectional view, taken on the line *x x*, illustrates the **U** formation of the superheater coils or tubes *e*, and shows how the ends are set into the drum *d* of the superheater. The coils *e* are set directly on each tube bank, and are so connected to the steam drum *d* that the steam is drawn from the drum and circulated through the superheater coils. As the coils are directly in the path of the hot gases, the temperature of the steam is greatly increased. To convey the steam from the drum and superheater, suitable piping and pipe flanges must be installed. In view (*c*) bent pipes *f* are shown connecting the steam space of the drum *a* and the flanges *g* of the superheaters; also, bent pipes *h* connect the main steam piping *i* with the steam outlets *j* of the superheaters. This arrangement of the superheater coils and pipe connections with large bends makes the installation flexible, so that the pipes and bends give readily with the expansion and contraction stresses arising in the operation of the boiler. The superheater outlet into the main steam pipe is fitted with a safety valve. View (*a*) shows a sectional view of the superheater tubes with the drum removed, and the full front view to the right of the center line indicates the position of the superheater drum, with the pipe flanges *j* and *g* riveted thereto.

81. For the purpose of cleaning the steam and water drums, manholes *k*, Fig. 44, are provided in the heads of the drums. These openings also give access to the boiler for inspection and repairs. The furnace is built for burning fuel oil and is lined with firebrick *l*. Oil-burning equipment, such as the oil piping and the burner nozzles *m*, is arranged at the front of the boiler. The boiler casing *n* is made of two thicknesses of sheet steel, with asbestos or some other non-conductor between.

Angle-iron stiffeners *o* give additional strength and stiffness to the casing. The smoke breeching *p* is placed at the rear of the boiler. Suitable clean-out doors *q* are provided in the casing for cleaning and inspection of the boiler parts.

82. Yarrow Water-Tube Boiler.—Another form of small-tube boiler, known as the Yarrow boiler, used in torpedo-boat service, is shown in Fig. 45. It consists of a large steam drum *a*,

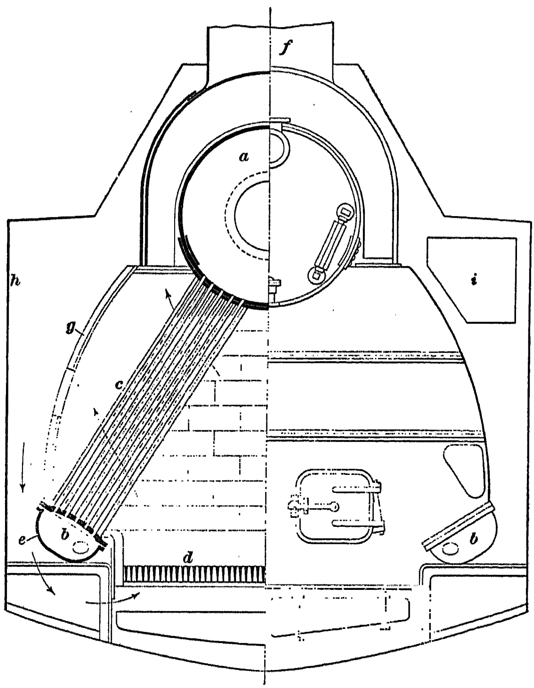


FIG. 45

with two smaller semicylindrical drums *b* below it and joined to it by inclined tubes *c*. The arrangement forms a triangle, with the grate *d* for the base. The lower drums have removable covers *e* for cleaning. The feedwater enters the steam drum below the water-line and descends through the inclined tubes most remote from the fire into the lower drum, deposits sediment, and rises through the tubes nearest the fire. The products

of combustion pass between the tubes to the smokestack *f* at the rear of the boiler. The boiler casing *g* is of iron and steel lined with non-conducting material. There is also an external casing *h* so arranged that before entering the furnace the air for supporting combustion enters the opening *i* and flows between the casings *g* and *h*. This aids materially in keeping down the temperature of the boiler room by preventing the radiation of heat.

83. Yarrow Water-Tube Boiler With Superheater.—A recent development of the Yarrow boiler adopted by the British Admiralty, is illustrated in the sectional view (*a*) and the side view (*b*), Fig. 46. It is installed with a superheater, and except for the lower drum construction, which is cylindrical in form, and the tube arrangement, it resembles the type just described. It is used for small speedy war vessels and large battleships and cruisers. The water, or generating, tubes *a* are straight, except the bottom row nearest the fire, which are bent. The tubes connect the water drums *b* and *c* to the steam and water drum *d*. As the water drums *b* and *c* are circular, the upper plate section *e* must be made heavier so that the tubes will have sufficient bearing area to insure steam-tight connections, and also to give the required strength to the tube-plate sections. The superheater drums *f* and *g* are also cylindrical and run parallel with the water drums *b* and *c*. The superheater tubes *h* are bent to a **U** shape and their ends are expanded into the superheater drums. To do this work to the best advantage, handhole plates *i* are installed opposite the superheater-tube openings, and through them the tubes are expanded. A downcomer *j* connects the drum *f* of the superheater with the steam pipe *k* inside the steam space of the boiler. Steam is drawn through the pipe *k* and the downcomer and circulates through the drum *f* and the tube sections of the superheater to the drum *g*, which is connected with the main steam stop-valve *l*. An auxiliary steam pipe *m* is also arranged in the steam space of the steam drum, to which is also fitted an auxiliary steam stop-valve *n*. The auxiliary steam feed piping and valve are used in case it is necessary to cut out the superheater for repairs.

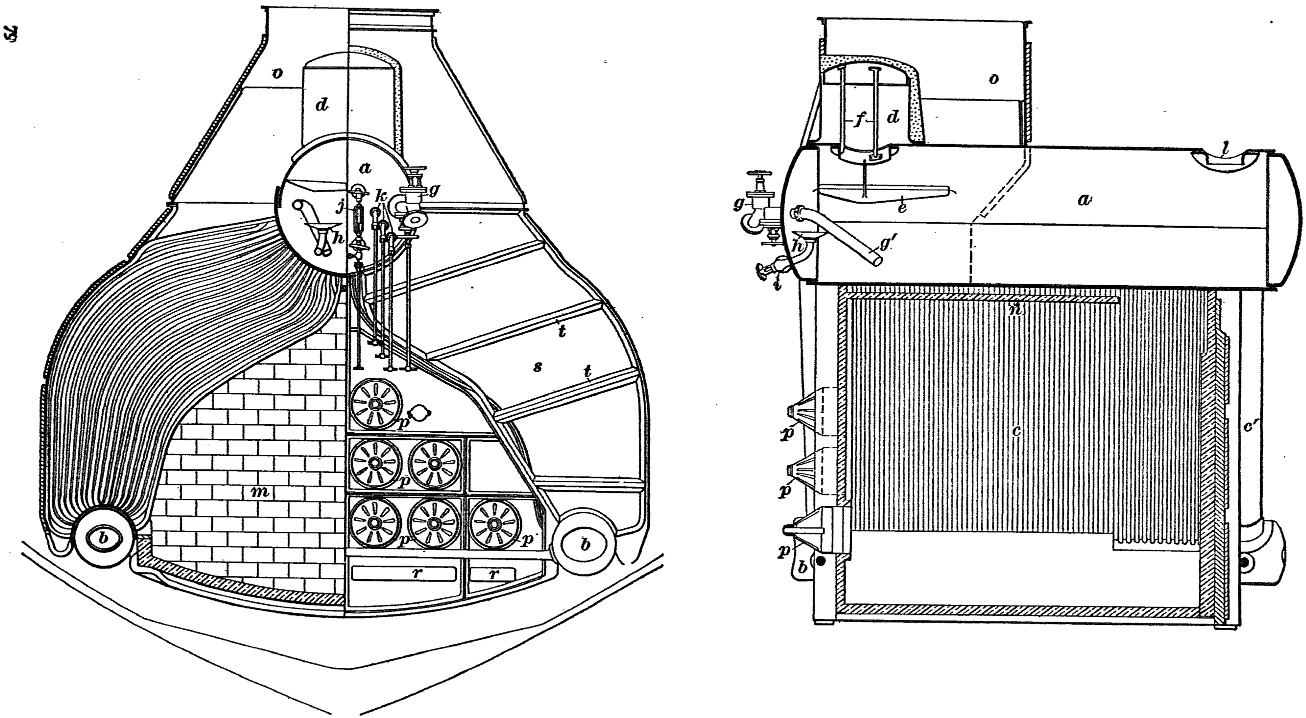
84. Feedwater enters the steam drum *d*, Fig. 46, through a perforated pipe *o*, or an auxiliary feed-pipe *p*. The arrangement of this piping is shown in the sectional view (*a*), and in view (*b*) is shown how far the perforated pipes extend into the drum. Feed check-valves are arranged in the feed piping as shown at *q* to prevent the feedwater from returning from the boiler into the feed piping. A gauge glass is placed at *r* and a scum blow-off valve at *s* with internal piping *t*. The scum blow-off is used to remove oil and other matter that collects on the surface of the water. At the bottom of the water drums is a blow-off valve *u*, connected to suitable piping, for the removal of mud and other sediment that collect in the water drums. Double safety valves *v* are connected to a flange riveted to the steam drum. One of the valves is set to blow at a slightly higher pressure than the other, so that, in case the first valve should not blow off and relieve the rising pressure within the boiler, the auxiliary valve will then blow and prevent an excess of steam pressure. Attached to the water drums and steam drum are zinc slabs arranged in trays *w* and supported by hangers that are riveted to the drums. The zinc offsets corrosion due to the galvanic action that arises in the boiler. The corroding elements attack the zinc plates instead of the boiler plates. Air and drain valves *x* are attached to the superheater drums, to relieve them of air or water of condensation that collects when the boiler is not in operation. In starting the boiler to meet sudden emergencies, these valves are opened, which allows the air and water to escape, and the steam circulates more freely in the superheating tubes.

85. The furnace of the boiler in Fig. 46 is constructed for burning fuel oil, and is lined with a special grade of firebrick that withstands very high temperatures. The baffle plates *y* cause the flame and products of combustion to circulate freely about the generating tubes and superheater before reaching the uptake or breeching *z*. The division plate *a′* separates the uptake into two parts and prevents the formation of eddies or back currents due to the meeting at this point of the gases from each side of the boiler. The funnel *b′* is directly attached to the

breeching, and where there are a number of boilers set in a battery, the breeching is made so that it receives the gases from all the boilers in the battery. This breeching connects directly with the stack. Fuel-oil burners c' are installed at the front of the boiler. Attached to the water drums are boiler supports d', shaped to fit the contour or outline of the drum shell and made with flat bases for bolting down. The boiler is covered with a steel jacket composed of two steel plates with asbestos between, and stiffened by angle irons. The exposed parts of the drums are covered with non-conducting material, commonly called *lagging*. The bottom of the furnace is composed of firebrick laid on steel plates e', called a pan. A layer of asbestos is placed between this plate and the bottom steel plate f'.

86. Normand Water-Tube Boiler.—The Normand boiler, shown in Fig. 47 (*a*) and (*b*), is considered one of the most efficient small-tube boilers. It is largely used in small war vessels of the speedy type by France and to some extent by the United States. The dry, or empty, weight of the boiler, as fitted for oil burning, with steam and water accessories, but not including the uptake and stack connections, is approximately 11 pounds per square foot of heating surface. The weight of water under steaming conditions is about 2 pounds per square foot of heating surface. The boiler is of the **A** type, having a main steam and water drum a and water drums b connected by generating tubes c and a downcomer c'. These tubes are small in diameter and bent so as to form an arch-shaped nest of tubes above the furnace. To the drum a is riveted a steam dome d. The steam in passing to the steam dome strikes the baffle plate e, which aids in preventing the very moist steam from entering the main steam outlet. The dome head is supported by the stays f. The feedwater enters the drum a through the valve connections g and piping g'.

87. A scum blow-off pan h, Fig. 47, is located at the given water level, as indicated in view (*a*), and a blow-off valve i is installed for the removal of scum, grease, and oil, as required. The gauge glass j is attached to the steam and water drum a and gauge-cocks k are also so placed that the water level can be



(a) Fig. 47 (b)

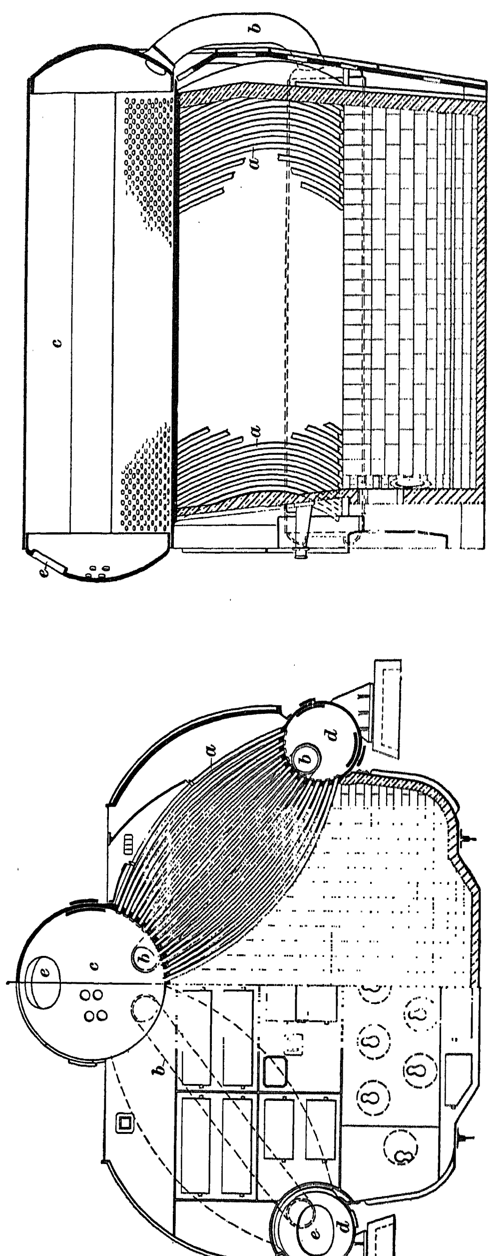


FIG. 43

readily determined. A manhole opening *l* is formed in the shell of the drum *a* and is so shaped that the flanged section around the manhole opening adds strength to and supports the shell plate of the drum. Manholes are also installed in the water drums *b*. The furnace is lined with firebrick *m* and the boiler tubes are baffled at *n* so that the gases pass entirely around the tubes and drum before entering the uptake *o*. Oil-burning apparatus *p* is arranged conveniently at the front of the boiler furnace. Clean-out doors *r* are installed in the boiler front for the removal of soot. The casing *s* is made of two steel plates, between which asbestos or other non-conducting material is placed. Angle-iron stiffeners *t* are used to give the necessary strength to the casing.

88. White-Forster Water-Tube Boiler.—The White-Forster boiler, shown in Fig. 48 (*a*) and (*b*), is also of the small-tube type. The generating tubes, or water tubes, *a* are all 1 inch in diameter, outside, and have a thickness of .104 inch. The downcomers *b* are 4¼ inches in diameter, outside, and have a thickness of .212 inch. The generating tubes *a* are bent and connect the steam and water drum *c* with the water drums *d*. The forward drum heads are fitted with manholes *e*, thus giving access to the drums for cleaning and repairs. The tubes are curved alike, as shown in the side view (*b*), and their arrangement and curvature are such that any tube or number of tubes can be readily removed through the manhole opening *e* in the steam drum *c* without affecting adjoining tubes. The tube holes in the drum *c* are larger than those in the drums *d*, to facilitate the work of installing tubes. As the tubes are curved when viewed from either the side or the front, stresses are not likely to affect the tubes by reason of expansion or contraction. The boiler furnace and casing are similar to those previously described, but there is no baffling of the gases. The boiler shown is arranged for oil burning. This type of boiler produces rapid evaporation of water without forcing the fires.

LOCOMOTIVE BOILERS

89. Classes of Locomotive Boilers.—The locomotive type of boiler is used to the exclusion of all other types in railroad work. It is made in three general forms, known as the *straight-top boiler*, the *extended wagon-top boiler*, and the *conical boiler*. Any one of these forms may have either a Belpaire firebox or a wide firebox.

90. Straight-Top Boiler With Wide Firebox.—In Fig. 49 is shown the straight-top locomotive boiler with wide firebox. The general construction is similar to the other types of locomotive boilers. The shell courses *a* are of uniform diameter, and as the courses are straight instead of tapering, the boiler is designated as a straight-top boiler. The firebox is known as the wide firebox on account of its shape, being shallow and extending beyond the driving wheels of the locomotive at the sides. A boiler of this shape, designed for burning anthracite, is known as the *Wooten firebox*. In some of the designs the roof sheet *b* slopes toward the back head *c* instead of being straight, as illustrated. The bottom of the shell course adjoining the firebox is also made tapering in some designs, to furnish more water space around the tubes and the forward end of the firebox. The back head *c*, throat sheet *d*, and door sheet *e* are flanged so as to fit the firebox side sheets properly. The door ring *f* is riveted to the flanges of the door openings in the back head and door sheet. The crown sheet *g* slopes toward the door sheet, to which it is riveted. Crown stays support the roof and crown sheet against internal pressure and the stays *h* support the flat surfaces of the side sheets and the heads of the firebox.

91. The back head is also supported by diagonal stays *i*, Fig. 49, which are attached to **T**-iron braces *j* that are riveted to the back head. A number of washout holes *k* are arranged in convenient places in the outer sheets of the firebox for the purpose of cleaning the crown sheet and removing mud and other sediment from the mud-ring *l*. The projecting lugs of the mud-ring at the back-head and throat-sheet ends are used to attach

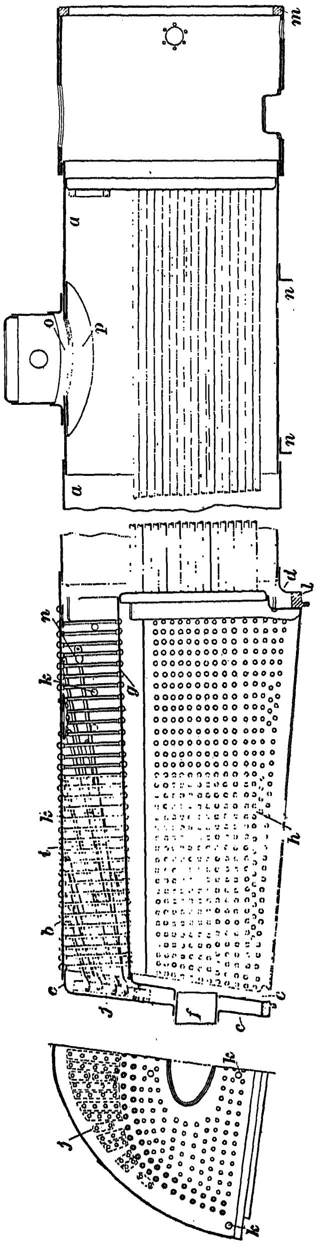


FIG. 49

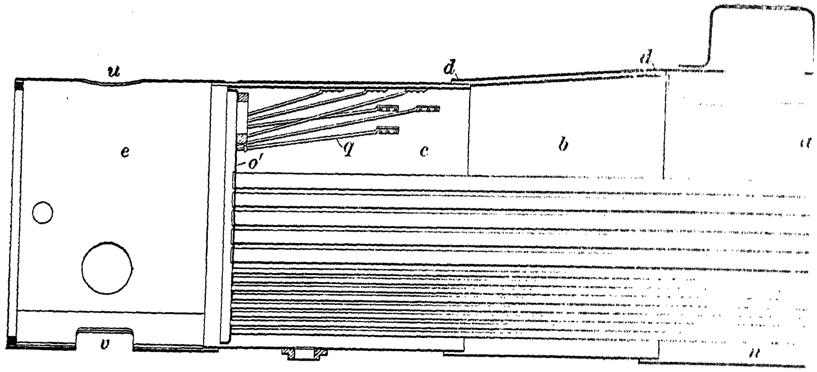
the ash-pan installed below the fire-box. A ring *m* at the front of the smokebox permits the attaching of the smokebox front. Gusset plates *n* are riveted to the bottom of the shell courses and used for bolting the boiler to the engine frame. The shell-plate opening *o* for the dome is reinforced by a steel-plate ring *p*, called a *dome stiffening ring*, which ring adds strength to the plate around the dome opening.

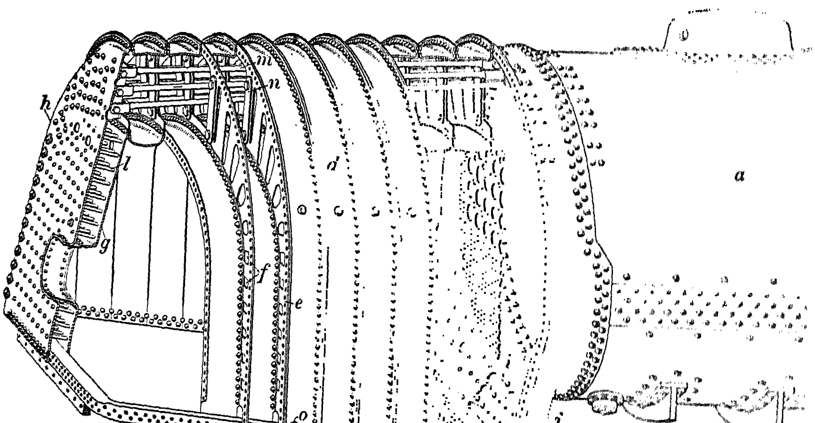
92. Extended Wagon-Top Boiler With Belpaire Firebox. The extended wagon-top boiler with a Belpaire firebox is shown in Fig. 50. The barrel section of the shell is made up of three sections *a*, *b*, and *c*, called *courses*, riveted together by circumferential seams *d*. The course *a*, next to the firebox, is cylindrical and is called the *dome course*. The course *b* is the *taper course*, as it is tapered so as to join the cylindrical courses *a* and *c*, which are not of the same diameter. The course *c* is commonly called the *first course*, and to the front of it is riveted the smokebox *e*. In the earlier designs, the taper course *b* extended to the firebox, and from this arrangement it was known as a wagon-top

boiler, its name being taken from the shape of the tapering top section of the course b. The dome in the wagon-top type was placed on the top of the firebox and required special staying. The use of the cylindrical shell a next to the firebox, and the setting of the taper course forward, permitted the dome to be installed on the cylindrical shell, in front of the firebox. To distinguish this arrangement of shell courses from the earlier wagon-top boilers, the type illustrated is called the extended wagon-top boiler.

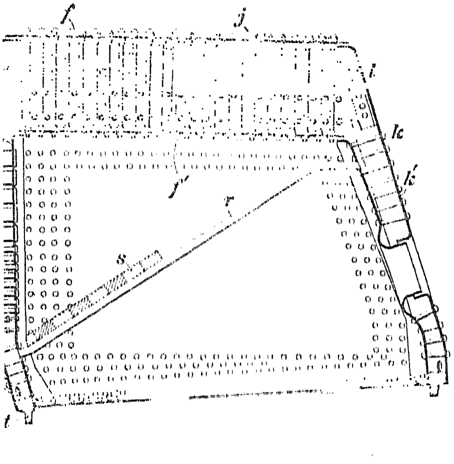
93. The firebox shown in Fig. 50 is known as the Belpaire firebox. The top sheet f, called the *roof sheet*, and the crown sheet f' are made flat, or with a slight curvature. The corners g of the crown sheet are bent to a slight radius, and sufficient material is allowed to form a lap joint, connecting the inside firebox side sheets h and the crown sheet. The roof-sheet corners g' are rolled to a larger radius and with depending sides that butt against the outer side sheets h'. By the use of cover-plates i and i', commonly called *welt straps* or *butt straps*, the joint is riveted, forming a butt joint. The inner and outer sheets of the firebox run practically parallel and their flat surfaces are supported by straight stays j. Transverse stays or cross-stays j' support the flat surfaces between the roof-sheet corners and the outer side sheets.

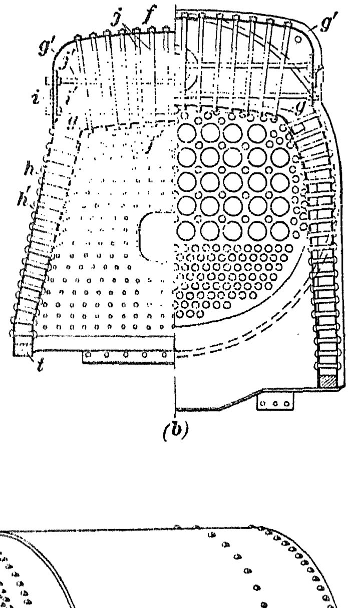
94. The door end of the inside firebox, Fig. 50, is closed with a flanged head k, called a *door sheet*, that has a flanged opening turned near the center of the head for the door connection. The outside head k', called the back head, is riveted to the outside side sheets. It is also flanged for the door opening so that when the two flanged heads are relatively arranged and riveted to the firebox, the flanges of the back head and the door sheet overlap to form a riveted connection called the door ring. The flat surface of the back head above the plane of the crown sheet is braced by **T** irons l. A flanged sheet m, called the throat sheet, connects the outside sheets of the firebox to the bottom of the shell a. The throat sheet is made in different shapes, depending on the form of the firebox. Usually it is flanged so that it fits around approximately one-half of the shell. For the



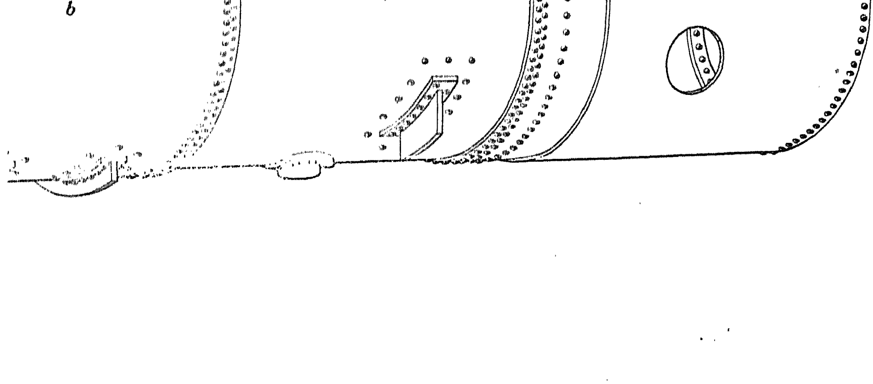


I L T 459—2173





(b)



installation of the tubes n and flues n', a firebox tube-sheet o and a front tube-sheet o' are drilled for the required number and diameter of tubes and stays. The tubes and flues extend from the firebox tube-sheet to the front tube-sheet. The tubes are 2 or $2\frac{1}{4}$ inches in diameter and the flues from $5\frac{3}{8}$ to $5\frac{1}{2}$ inches in diameter. The superheater tubes are placed inside the flues and extend from the smokebox to the firebox tube-sheet. The flat section of the firebox tube-sheet o is supported by stays p called *belly,* or *throat, stays* and the segment of the front tube-sheet o' above the tubes is supported by gusset stays or diagonal braces q.

95. In the firebox, Fig. 50, bent tubes r, called *arch tubes,* extend from the firebox tube-sheet to the back head. The ends of the tubes terminate in the water space so that water will circulate freely in the tubes. The tubes form a support for a firebrick arch s that causes the fuel gases to mix with the air more thoroughly, thus inducing a more complete combustion of the gases before they strike the tubes. It also prevents cold-air blasts, which enter through the fire-door during the period of firing, from striking directly into the boiler tubes, and thus reduces the stresses that otherwise would arise from the contraction of the boiler plates. The bottom of the firebox is closed with a wrought-iron ring t, called the mud-ring.

96. The gases of combustion pass directly from the furnace, Fig. 50, through the tubes and flues to the smokebox e, and out of the stack opening u. In locomotives, a strong draft is produced by allowing the exhaust steam from the engine to discharge through the smokestack. The exhaust nozzle is placed below the stack entering through the opening v. The escaping steam from the nozzle carries with it the air and gases in the smokebox, drawing the gases from the furnace and thus increasing the draft in the furnace and tubes.

97. Conical Boiler With Jacobs-Shupert Firebox.—The conical boiler, Fig. 51, is of similar construction to those already described. It is made up of a cylindrical course a, of uniform diameter, attached next to the firebox. A taper course b having a uniform taper is employed to connect the shell course a with

the first shell course *c*. From this arrangement of the shell courses, the term conical boiler has been given to designate the boiler.

The Jacobs-Shupert firebox shown in the illustration is a patented sectional firebox having the inner and outer sides and top made up of a series of bent channel shapes *d* with depending flanges. Between the channels and riveted thereto are stay sheets *e*. By the use of this construction, no additional staying of the side sheets is required. To permit circulation of the steam and water between the channels, openings *f* are cut in the stay sheets *e*. The door sheet *g*, back head *h*, tube-sheet *i*, and throat sheet *j* are flanged so as to fit the upright flanges of the channels, to which they are riveted, as shown. The bottom edges of these sheets are straight and are riveted to the mud-ring *k*. The back head and door sheet are stayed together with the screw stays *l*, and the upper section of the back head, which is a flat plate, is supported by the diagonal stays *m*. The stay plates *e* are cut out so as to allow the diagonal stays to extend from the roof of the firebox to the back head. Sling stays *n* are used to stay the sections of the channel plate, left weakened by the removal of the solid plate sections of the sheets. Wash-out plugs *o* are installed above the mud-ring and in the outside channel sections in line with the crown sheet of the inside fire-box plates.

98. The tubes of locomotive boilers range from 6 to 22 feet in length, and may be made of steel or iron. The tubes of stationary boilers of this type are usually 3 to 3½ inches in diameter. The tubes of stationary locomotive boilers are not spaced as closely as in locomotive boilers of the railroad type. With the smaller diameter and larger number of tubes, steam is generated more rapidly than in the stationary types, small tubes proving more efficient in breaking up the fuel gases and in conducting the heat more effectively to the large body of water in the boiler.

BOILER MOUNTINGS

SAFETY DEVICES

SAFETY VALVES

FORMS OF SAFETY VALVES

1. Purpose of Safety Valve.—A safety valve is attached to a boiler to prevent the steam pressure from rising above a certain safe limit. If steam is generated faster than it is used, it will accumulate in the boiler, causing increased pressure; and if the increase of pressure beyond a safe limit is not prevented, a rupture of the boiler or an explosion may result. It is the work of the safety valve to allow the excess of steam to escape, thus automatically reducing the pressure. To do this, the valve or valves must be of such size as to permit steam to escape at least as rapidly as it is formed in the boiler. Otherwise, the steam pressure will continue to rise, even though the safety valve is open, and will result in stresses that may lead to a rupture of some part of the boiler or to an explosion.

2. Classes of Safety Valves.—A safety valve consists of a valve disk held down on its seat by pressure applied in one of several ways and acted on underneath by the pressure of the steam in the boiler to which the safety valve is attached. As long as the downward pressure exceeds the upward pressure, the valve remains closed; but when the upward pressure becomes greater than the downward pressure, the disk is forced up off its seat, and some of the accumulated steam escapes,

thereby lowering the pressure in the boiler. When the pressure is lowered to such an extent that the upward pressure on the disk no longer exceeds the downward pressure, the valve closes. There are three ways of applying pressure to the disk to hold it to its seat: (*a*) By a dead-weight; (*b*) by a weight acting on a lever, and (*c*) by the action of a spring. According to these methods of applying the downward pressure, safety valves are divided into three classes, known as *dead-weight safety valves*, *lever safety valves*, and *spring-loaded*, or *pop*, *safety valves*, respectively. The dead-weight type is used only on boilers that carry low pressures, such as heating boilers. It consists of a valve attached to a vertical stem on which are placed a number of disk-shaped weights, the valve being held to its seat by the dead-weight of the disks. On vessels that carry high steam pressures, the lever and the pop types are used.

3. Lever Safety Valve.—A form of lever safety valve is shown, partly in section, in Fig. 1. It consists of an iron body *a* with a heavy flange *b* by which it is connected to the boiler, and a flange *c* to which is connected the pipe through which the steam escapes. In the body of the valve is fastened the beveled seat *d*, on which rests the beveled disk *e*. The disk is connected to a stem *f* that passes through the cover *g* and is formed into a yoke *h* at its upper end. The lever *i* (which is broken away at the middle, so that its full length is not shown in the illustration) passes through the yoke *h* and is fulcrumed at one end on the pin *j*, held in a bracket that forms part of the cover *g*. On the other end of the lever is hung a weight *k*, consisting of a cast-iron ball, which may be moved

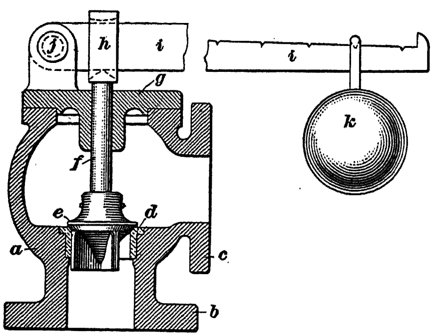


FIG. 1

along the lever. The weight of the ball puts a downward pressure on the stem *f* and tends to hold the valve disk *e* to its seat. Steam from the boiler enters the space below the valve and tends to force the disk upwards, off its seat. By shifting the ball *k*, any desired pressure may be put on the stem *f* and the disk *e*, and thus the valve may be set to open when the steam pressure reaches a certain point.

4. Safety valves of the lever and dead-weight types are not looked upon with favor by engineers. There is always danger that the stem of the valve may stick in its guide and thus increase the pressure at which the valve will open; the weight on the lever may be shifted accidentally and thus change the blow-off pressure; or ignorant boiler attendants may add weights so as to obtain a higher working pressure in the boiler, regardless of the ability of the boiler to withstand the increased pressure.

The use of lever safety valves or dead-weight safety valves is not permitted under the rules of the American Society of Mechanical Engineers, commonly referred to as the *A. S. M. E. Boiler Code.*

5. Pop Safety Valves.—Lever and dead-weight safety valves have been superseded by pop safety valves. In the pop safety valve, the pressure by which the valve disk is held to its seat is obtained by a helical spring made of steel. The valve disk is made of metal that will not corrode, so as to avoid the danger of having the disk stick to its seat when in service. The disk and its seat may be flat, or both may be beveled at an angle of 45°. Pop valves of different types are made for use on stationary, marine, and locomotive boilers; also, valves for use with superheated steam differ from those for use with saturated steam. Valves for superheated steam have larger springs and in order that they may not be affected by the higher temperature, the springs are not incased in the body of the valve. Such valves may also be used to advantage with high-pressure saturated steam.

6. Pop Safety Valves for Stationary Boilers.—The pop safety valve shown in section in Fig. 2 is intended for use on

a stationary boiler generating saturated steam. The valve *a* is held to its seat *b* by the helical spring *c*, which is made of crucible steel. A stem *d* fits into a socket in the valve *a* and carries a collar *e* against which the pressure of the spring is exerted. A similar collar *f* bears on the upper end of the spring. The spring is completely enclosed by the casing *g*, which is part of the casting that forms the cover of the safety valve. The upper collar *f* is adjustable and may be forced down by turning down the screw *h*, this operation putting greater compression on the spring, forcing the valve more firmly to its seat, and thus raising the pressure at which the safety valve will open. Backing out the screw *h*, so as to allow the collar *f* to rise, decreases the compression on the spring and makes the valve open at a lower pressure. After the adjustment has been made, the locknut *i* is tightened so as to hold the screw *h* in a fixed position. The screw *h* is a sleeve that forms a guide for the upper end of the stem *d*.

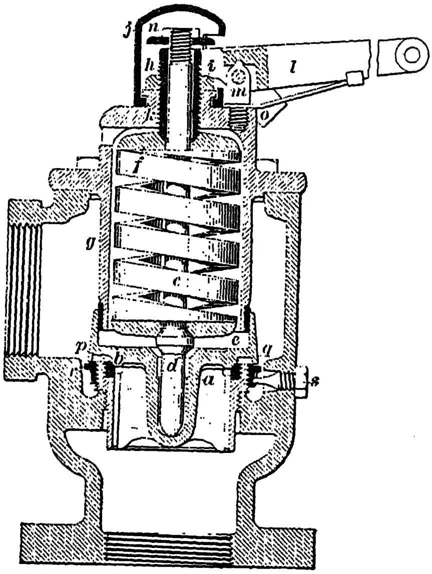


FIG. 2

7. A cap *j*, Fig. 2, is fixed permanently over the upper ends of the valve stem and the adjusting screw by having a lip forced into a groove *k* around the upper end of the valve cover. In the side of the cap is a slot just wide enough to admit the forked end of the lever *l*, which is pivoted on a pin *m*. The forked end fits around the stem *d* beneath the collar *n*, which is screwed to the upper end of the stem. By depressing

the outer end of the lever *l*, the stem *d* is raised, the pressure of the spring is removed from the valve, and the steam pressure beneath will then open the valve. This forms a method of testing the safety valve to see whether it is in working order. The pin *m* is drilled to receive the bow of a padlock *o*. No adjustment of the screw *h* can be made until the lever *l* is removed, which is done by taking out the pin *m*. The pressure at which the valve will blow off is fixed at the factory, and the valve is locked. No adjustment of the blow-off pressure can be made thereafter, except by the boiler inspector and under his supervision.

8. The upper part of the valve *a*, Fig. 2, is made with a sleeve that fits around the lower end of the casing *g*, thus forming a closed chamber for the protection of the spring. An annular space *p* is formed in the valve face, just outside the seat, and inside the lip *q*. When the steam pressure beneath is just on the point of raising the valve, the first steam to escape past the seat collects in this annular space. The area of valve surface exposed to steam pressure is thus increased, and the valve is lifted suddenly, or with a pop. It is from this sudden opening of the valve that the pop safety valve derives its name. The valve and its seat are shown beveled to an angle of 45°. Sometimes the seat is ball-ground; that is, it is ground with a curved face that is part of a spherical surface. The valve is then ground to the same curvature. The advantage of this construction is that the valve and the seat will always have a perfect bearing, even if the valve gets slightly out of alinement.

9. The extent of the reduction of pressure, or the difference between the pressure at which a safety valve opens and the pressure at which it closes, is called the *blow-down*. With the valve shown in Fig. 2, the amount of blow-down may be regulated by the adjusting ring *r*. This ring is threaded and is screwed over the seat ring, and its outer edge is notched all around. If the plug *s* is removed, a rod may be inserted, engaging with the notches, and the ring may be turned. If the ring *r* is turned up, the amount of blow-down will be

increased; that is, the drop of pressure between the opening and the closing of the valve will be made greater. If the ring is turned down, the blow-down will be decreased. A properly adjusted pop safety valve opens sharply and closes promptly, preventing undue loss of steam.

10. A pop safety valve for use on a stationary boiler that generates superheated steam is shown in Fig. 3. Its internal construction is almost exactly like that of the type just described; but the shape of the body is different, and the spring is not enclosed, so that it will not be affected by the high temperature met with in connection with superheated steam. The valve is locked, so as to prevent unauthorized changing of the blow-off pressure; also, it is sealed with a brass tag *a*, on which is stamped the number of pounds of steam that can escape through the valve in an hour, known as the *steam-relieving capacity* of the valve. A safety valve should always be attached to a superheater, and set to blow at a pressure slightly below that at which the safety valve on the boiler will blow. Then, if the engines or turbines are shut down, or the amount of steam used is suddenly decreased, the resultant rise of pressure will cause the safety valve on the superheater to open, and steam will escape by way of the superheater, thus preventing the overheating or burning of the superheater tubes.

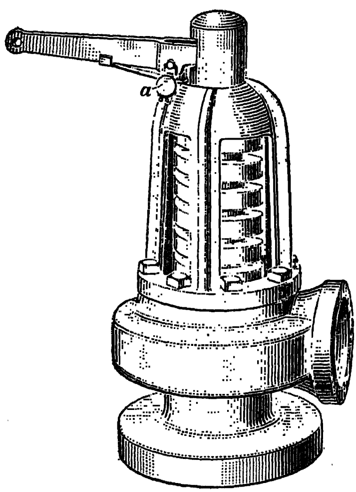


FIG. 3

11. Safety Valves for Marine Boilers.—Safety valves for marine boilers are similar to the pop valves used on stationary boilers and are made with either enclosed or exposed springs, according to the service demanded. They may be mounted

separately on the boiler or in pairs on **Y** fittings; or, two or more valves may be incorporated in one valve body, in which case the safety valve is known as a duplex, triplex, or multiplex valve.

If two or more valves are connected separately to the boiler or the steam drum, an opening must be cut for each valve. To avoid this when two valves are to be installed, the arrangement shown in Fig. 4 may be used. One opening is

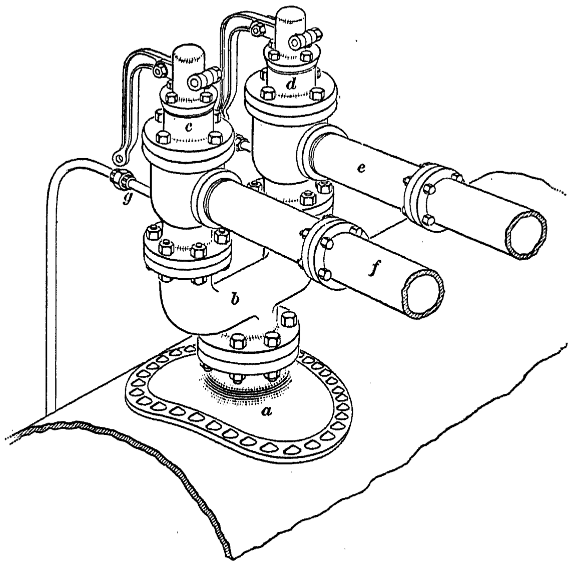


Fig. 4

cut in the shell and over it is riveted the nozzle *a*. To this nozzle is bolted the branch fitting *b* that carries the safety valves *c* and *d*. Pipes *e* and *f* lead from the valves to the main exhaust, and these pipes must be supported in such a way as to put no stress on the valves. To prevent accumulation of condensation on top of the valves, drain pipes *g* are supplied.

A duplex valve for use with superheated steam is shown in Fig. 5. The two valves *a* and *b* are installed on one body *c*.

12. Locomotive-Boiler Safety Valves.—Locomotive boilers are subjected to a service entirely different from that of

stationary and marine boilers, for they must produce steam very rapidly so as to take care of variable loads. As a result, the locomotive safety valve will frequently be in almost continual action. The feed-water in some localities is very poor, and may therefore cause scale to accumulate around the working parts, thus necessitating frequent cleaning of the safety valve. On account of the hard usage to which the valve is subjected, it must be designed to withstand the frequent blow-off action and must be of a form that readily permits repairs and cleaning operations.

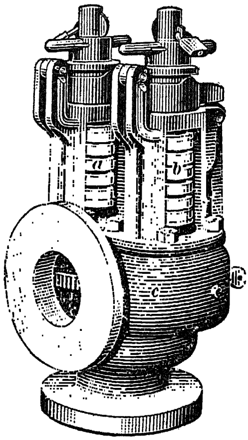
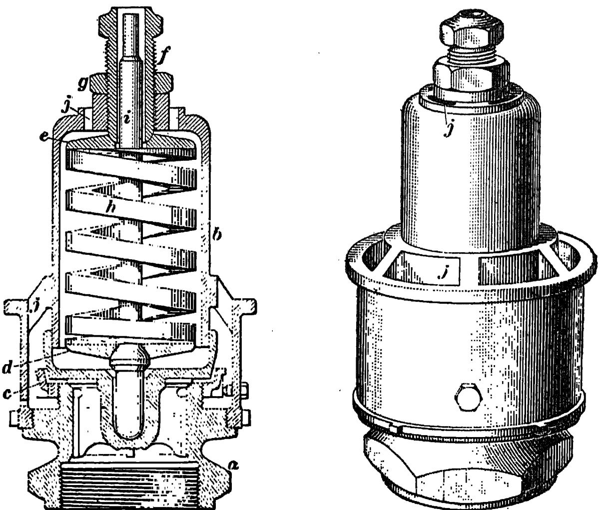


FIG. 5

A locomotive-boiler safety valve with encased spring is illustrated in Fig. 6 (*a*) and (*b*). In construction it is similar to the types of safety valves already described, except that the blow-off is at the top instead of at the side. The valve base *a*, case *b*, adjusting ring *c*, spring washers *d* and *e*, compression screw *f*, and check-nut *g* are made of bronze; and the spring *h* and the spindle *i* are made of steel. View (*b*) shows the arrangement of the steam discharge outlets *j*, which makes it possible for the steam to rise vertically, thus preventing spreading of the escaping steam, which would cloud cab windows and handicap the men operating the locomotive. Locomotive safety valves may also be fitted with mufflers to reduce the noise made by the steam while blowing off. The muffler is made of bronze, in the form of a shell, and is mounted over the body of the safety valve. To allow the escape of the steam, numerous openings are drilled in the muffler.

13. Use and Care of Safety Valves.—The safety valve must be connected directly to the boiler, steam drum, or superheater, so that there is no possible chance of cutting off communication between the boiler and the valve. The cross-

sectional area of the safety-valve nozzles or saddles and the close nipples (short sections of threaded pipe) that are used with valves having screwed flanges should not be less than that of the valve inlet. No valve of any kind should be placed between the safety valve and the boiler. A new boiler should be blown down and cleaned before the safety valve is used,



(a) (b)

FIG. 6

otherwise, boiler-plate chips that might be left in the boiler, and other refuse, such as red lead, waste, etc., may get into the valve seat and injure it. During the hydrostatic test of the boiler, the safety valve should be gagged, instead of having the compression of the spring increased to hold the valve shut. This may be done by the use of a clamp that pulls the spring down, thus forcing the valve to hold its seat. A far better plan is to remove the valve and plug the safety-valve opening during the test.

14. Safety-Valve Rules and Regulations.—Safety valves on government marine boilers must meet the requirements fixed by the rules and regulations of the United States Board of

Supervising Inspectors. Safety valves used in stationary power plants in the United States must be made and installed in accordance with the rules of the state in which the boilers are operated. The rules of the American Society of Mechanical Engineers have been adopted by most of the states; therefore, the following data relating to the capacity, installation, and adjustment of the safety valve are taken from the A. S. M. E. Boiler Code.

Safety Valve Requirements

Each boiler having more than either 500 square feet of water-heating surface, or in which the generating capacity exceeds 2,000 pounds per hour, shall have two or more safety valves. (The method of computing the relieving capacity of the safety valves according to the A. S. M. E. requirements is given in Art. **19**.)

The safety-valve capacity for each boiler shall be such that the safety valve or valves will discharge all the steam that can be generated by the boiler without allowing the pressure to rise more than 6 per cent. above the maximum allowable working pressure, or more than 6 per cent. above the highest pressure to which any valve is set.

One or more safety valves on every boiler shall be set at or below the maximum allowable working pressure. The remaining valves may be set within a range of 3 per cent. above the maximum allowable working pressure, but the range of setting of all of the valves on a boiler shall not exceed 10 per cent. of the highest pressure to which any valve is set.

All safety valves shall be so constructed that no shocks detrimental to the valve or to the boiler are produced and so that no failure of any part can obstruct the free and full discharge of steam from the valve. Safety valves may be of the direct spring-loaded pop type, with seat and bearing surface of the disk inclined at any angle between 45° and 90°, inclusive, to the center line of the spindle. The maximum rated capacity of a safety valve shall be determined at a pressure of 3 per cent. in excess of that at which the valve is set to blow and with a blow-down of not more than 4 per cent. of the set pressure, the blow-down to be in no case less than 2 pounds.

Safety valves may be used which give any opening up to the full discharge capacity of the area of the opening of the inlet of the valve, provided the movement of the valve is such as not to induce lifting of the water in the boiler.

Dead-weight and weighted-lever safety valves shall not be used.

Each safety valve ½ inch in size and larger shall be plainly marked by the manufacturer. The marking may be stamped or cast on the casing, or stamped or cast on a plate or plates securely fastened to the casing, and shall contain the following markings:

(*a*) The name or identifying trade mark of the manufacturer.
(*b*) The pipe size of valve inlet.
(*c*) The steam pressure at which it is to blow.
(*d*) Blow-down, or difference between the opening and closing pressures.
(*e*) The weight of steam discharged in pounds per hour at a pressure 3 per cent. higher than that for which the valve is set to blow.
(*f*) A. S. M. E. Standard.

The minimum aggregate relieving capacity of all the safety valves on a boiler shall be determined on the basis of 6 pounds of steam per hour per square foot of boiler heating surface for water-tube boilers. For all other types of power boilers, the minimum allowable relieving capacity shall be determined on the basis of 5 pounds of steam per hour per square foot of boiler heating surface for boilers with maximum allowable working pressure above 100 pounds, and on the basis of 3 pounds of steam per hour per square foot of boiler heating surface for boilers with maximum allowable working pressures at or below 100 pounds per square inch.

The heating surface shall be computed for that side of the boiler surface exposed to the products of combustion, exclusive of the superheating surface. In computing the heating surface for this purpose, only the tubes, fireboxes, shells, tube-sheets, and the projected area of the headers need be considered. The minimum number and size of safety valves required shall be determined on the basis of the aggregate relieving capacity and the relieving capacity marked on the valves by the manufacturer.

If the safety-valve capacity cannot be computed, or if it is desirable to prove the computations, it may be checked in any one of the three following ways, and if found insufficient, additional capacity shall be provided:

(*a*) By making an accumulation test; that is, by shutting off all other steam discharge outlets from the boiler and forcing the fires to the maximum. The safety-valve equipment shall be sufficient to prevent an excess pressure beyond that specified in the second paragraph of these requirements.

(*b*) By measuring the maximum amount of fuel that can be burned and computing the corresponding evaporative capacity on the basis of the heating value of the fuel.

(*c*) By determining the maximum evaporative capacity by measuring the feedwater. The sum of the safety-valve capacities marked on the valves shall be equal to or greater than the maximum evaporative capacity of the boiler.

When two or more safety valves are used on a boiler, they may be mounted either separately or as twin valves made by placing individual valves on **Y** bases, or duplex, triplex, or multiplex valves having two or more valves in the same body casing. The valves shall be made of equal sizes, if possible, and in any event if not of the same size, the smaller of the two valves shall have a relieving capacity of at least 50 per cent. of that of the larger valve.

The safety valve or valves shall be connected to the boiler independent of any other steam connection, and attached as close as possible to the boiler, without any unnecessary intervening pipe or fitting. Every safety valve shall be connected so as to stand in an upright position, with spindle vertical, when possible.

The opening or connection between the boiler and the safety valve shall have at least the area of the valve inlet. No valve of any description shall be placed between the required safety valve or valves and the boiler, nor on the discharge pipe between the safety valve and the atmosphere. When a discharge pipe is used, the cross-sectional area shall not be less than the full area of the valve outlet or of the total of the areas of the valve outlets discharging thereinto, and shall be as short and straight as possible and so arranged as to avoid undue stresses on the valve or valves.

All safety-valve discharges shall be so located or piped as to be carried clear from running boards or platforms. Ample provision for gravity drain shall be made in the discharge pipe, at or near each safety valve, and where water of condensation may collect. Each valve shall have an open gravity drain through the casing below the level of the valve seat. For iron- and steel-bodied valves exceeding 2 inches in size, the drain holes shall be tapped.

If a muffler is used on a safety valve it shall have sufficient outlet area to prevent back pressure from interfering with the proper operation and discharge capacity of the valve. The muffler plates or other devices shall be so constructed as to avoid any possibility of restriction of the steam passages due to deposit.

When a boiler is fitted with two or more safety valves on one connection, this connection to the boiler shall have a cross-sectional area not less than the combined areas of inlet connections of all of the safety valves with which it connects.

Safety valves shall operate without chattering and shall be set and adjusted as follows: To close after blowing down not more than 4 per cent. of the set pressure but not less than 2 pounds in any case. For spring-loaded pop valves operating on pressures up to and including 300 pounds per square inch the blow-down shall not be less than 2 per cent. of the set pressure. To insure guaranteed capacity and satisfactory operation, the blow-down as marked upon the valve shall not be reduced.

To insure the valve being free, each safety valve on boilers with maximum allowable working pressures up to and including 200 pounds per square inch, shall have a substantial lifting device by which the valve disk may be positively lifted from its seat at least $\frac{1}{16}$ inch when there is no pressure on the boiler. For boilers with working pressures above 200 pounds per square inch, the safety-valve lifting device need not provide for lifting the valve disk $\frac{1}{16}$ inch except at such times as there is at least 75 per cent. of the full working pressure on the boiler.

The seats and disks of safety valves shall be of suitable material to resist corrosion. The seat of a safety valve shall be fastened to the body of the valve in such a way that there is no possibility of the seat lifting.

Springs used in safety valves shall not show a permanent set exceeding $\frac{1}{16}$ inch ten minutes after being released from a cold compression test closing the spring solid. The spring shall be so constructed that the valve can lift from its seat at least $\frac{1}{10}$ the diameter of the seat before the coils are closed or before there is other interference.

The spring in a safety valve shall not be used for any pressure more than 10 per cent. above or below that for which it was designed.

A safety valve over 3-inch size, used for pressures greater than 15 pounds per square inch gauge shall have a flanged inlet connection. The dimensions of flanges subjected to boiler pressures not exceeding 250 pounds per square inch shall conform to the American Extra-Heavy Standard, except that the face of the safety-valve flange and the nozzle to which it is attached may be flat and without the raised face.

Every superheater shall have one or more safety valves near the outlet. The discharge capacity of the safety valve or valves on an attached superheater may be included in determining the number and size of the safety valves for the boiler, provided there are no intervening valves between the superheater safety valve and the boiler, and provided the discharge capacity of the safety valve or valves on the boiler, as distinct from the superheater, is at least 75 per cent. of the aggregate valve capacity required.

Every safety valve used on a superheater, discharging superheated steam, shall have a steel body with a flanged inlet connection, and shall have the seat and disk of nickel composition or equivalent material, and the spring fully exposed outside of the valve casing so that it shall be protected from contact with the escaping steam.

Every boiler shall have proper outlet connections for the required safety valve or valves, independent of any other outside steam connection, the area of the opening to be at least equal to the aggregate areas of inlet connections of all of the safety valves to be attached thereto. An internal collecting pipe, splash plate, or pan may be used, provided the total area for inlet of steam thereto is not less than twice the aggregate areas of the inlet connections of the attached safety valves. The holes in such collecting pipes shall be at least $\frac{1}{4}$ inch in diameter and the least dimension in any other form of opening for inlet of steam shall be $\frac{1}{4}$ inch.

SAFETY-VALVE CALCULATIONS

15. Lever Safety-Valve Calculations.—No safety valve can open without a slight increase of pressure above that for which it is set; since, in order to lift the valve, the pressure on the under side of the valve, which may be called the internal,

or upward, force, must exceed the external, or downward, force on the valve plus the friction of the mechanism of the valve. If the internal and the external forces on the valve are equal, the valve will be balanced, and an increase of the internal force will cause it to open. A safety valve will not close until the pressure has been reduced somewhat below the pressure at which the valve opened.

The point at which a safety valve will blow off depends on the external force on the valve. To be balanced, or in equilibrium, the external load exerting a downward pressure on the valve must be equal to the internal force exerting an upward pressure on the under face of the valve. Evidently, the upward pressure is equal to the area of the valve multiplied by the pressure per unit of area.

16. Spring-loaded safety valves are always adjusted by comparison with an accurate steam gauge, and this practice is now generally employed when setting the lever safety valve. If it were possible to measure all the parts of the lever safety valve accurately, it might be finally adjusted in accordance with calculations based on such measurements. However, a slight inaccuracy of measurement of one or more of the parts may produce a considerable error, even though the figuring is correctly done. Because of this, calculations regarding the position of the weight on the lever of a lever safety valve are in practice considered as giving only an approximate, or trial, position of the weight on the lever.

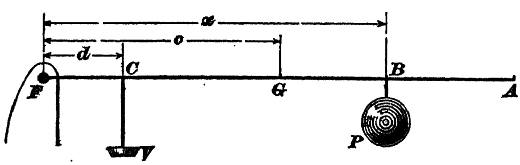


FIG. 7

17. Referring to Fig. 7, the distance from the fulcrum F to the end A of the lever is the over-all length of the lever; this is used only for finding the distance c of the center of gravity G of the lever from the fulcrum F. When the lever is straight and of the same width and thickness throughout, the

distance c is one-half the over-all length of the lever; for any other case the distance c is determined in practice by balancing the lever over a knife edge. The distance x from the fulcrum to the point of attachment B of the weight P is often called the *length of the lever*, but on account of the liability of confusing this term with the end-to-end length of the lever, it is not used here. The distance d is the distance between the fulcrum F and the center line of the valve stem C of the valve V.

Let A = area of valve, in square inches;
d = distance from center line of valve to fulcrum, in inches;
x = distance of weight from fulcrum, in inches;
p = steam pressure, in pounds per square inch;
P = weight of load or weight on lever, in pounds;
V = weight of valve and stem, in pounds;
w = weight of lever, in pounds;
c = distance from fulcrum to center of gravity of lever, in inches.

To find the pressure for which a lever safety valve is set, use the formula

$$p=\frac{Px+wc+Vd}{Ad} \qquad (1)$$

To find the weight necessary on a safety-valve lever, use the formula

$$P=\frac{pAd-(wc+Vd)}{x} \qquad (2)$$

To find at what distance from the fulcrum the weight must be put, use the formula

$$x=\frac{pAd-(wc+Vd)}{P} \qquad (3)$$

EXAMPLE 1.—At what pressure will a safety valve having a diameter of 4 inches blow off, when the weight of the valve and stem is 10 pounds; of the lever, 20 pounds; and of the ball, 120 pounds? The total length of the lever, which is straight and of uniform section, is 44 inches; the weight is 40 inches from the fulcrum, and the distance from the center line of the valve to the fulcrum is 4 inches.

SOLUTION.—The area of the valve is $A=4^2\times.7854$. As the lever is straight, the distance c from the fulcrum to the center of gravity is taken as one-half its length, or $\frac{44}{2}$. Apply formula **1**, and

$$P=\frac{120\times40+20\times\frac{44}{2}+10\times4}{4^2\times.7854\times4}=105 \text{ lb. per sq. in., nearly. Ans.}$$

EXAMPLE 2.—With a safety valve having the dimensions given in example 1, what weight is necessary to have the valve about to blow off at a steam pressure of 100 pounds per square inch?

SOLUTION.—Apply formula **2**, and

$$W=\frac{4^2\times.7854\times100\times4-(20\times\frac{44}{2}+10\times4)}{40}=113.66 \text{ lb. Ans.}$$

EXAMPLE 3.—A safety valve has an area of 11 square inches; the distance from the center line of the valve to the fulcrum is 3 inches; the steam pressure, 40 pounds per square inch; the weight weighs 50 pounds; the lever is straight and parallel, 32 inches long, and weighs 15 pounds; the valve and stem weigh 6 pounds. How far from the fulcrum must the weight be placed?

SOLUTION.—Apply formula **3**, and

$$L=\frac{11\times40\times3-(15\times\frac{32}{2}+6\times3)}{50}=21.24 \text{ in. Ans.}$$

A candidate for American marine engineer's license should thoroughly familiarize himself with the calculations pertaining to a lever safety valve, as a candidate for a marine engineer's license must be rejected by the examining inspectors if he fails to solve safety-valve problems similar to those given in the preceding examples.

18. Spring Safety-Valve Calculations.—The question often arises as to the pressure for which a safety-valve steel spring is intended. When made with 13 complete turns, the standard prescribed, the question can be answered by an application of the rule of the Board of Trade, Great Britain, governing this problem.

Rule.—*To find the steam pressure for which a spring is intended, cube the diameter, in inches, of the wire, if round, or the side of square, if square, and multiply by 8,000 for round wire and 11,000 for square wire. Divide the product by the product of the diameter of the spring, in inches, measured from center to center of the wire, and the area of the safety valve.*

Stated as a formula,

$$P = \frac{d^3 c}{D A}$$

in which P = steam pressure, in pounds per square inch;
d = diameter, or side of square, of wire, in inches;
c = 8,000 for round wire and 11,000 for square wire;
D = diameter of spring from center to center of wire;
A = area of safety valve, in square inches.

EXAMPLE.—For what pressure is a spring made of square wire measuring $\frac{1}{2}$ inch and 3 inches in diameter intended, if the valve has an area of 6 square inches?

SOLUTION.—Apply the formula, and

$$P = \frac{.5^3 \times 11{,}000}{3 \times 6} = 76.4 \text{ lb. per sq. in.} \quad \text{Ans.}$$

Spring-loaded safety valves are finally adjusted under pressure by comparison with an accurate steam gauge, the tension of the spring being increased or diminished until the valve opens at the desired pressure. The rule given will show the approximate pressure for which the spring can be used.

19. Methods of Checking Safety-Valve Capacity.—The discharge capacity of a safety valve must be sufficient at least to take care of the maximum boiler evaporation. According to the A. S. M. E. Boiler Code, the safety-valve capacity may be determined by measuring the maximum amount of fuel that can be burned and substituting the value in the formula

$$W = \frac{.75\, C H}{1{,}100}$$

in which W = weight of steam generated per hour, in pounds;
C = total weight (or volume) of fuel burned per hour at time of maximum forcing, in pounds (or cubic feet);
H = heat of combustion of the fuel, in B. t. u. per pound (or cubic foot).

In the formula, the term .75 represents an average boiler efficiency and the term 1,100 represents the average number of

heat units required to convert a pound of feedwater into steam. The value of C is found by making a test to determine

TABLE I

HEATING VALUES OF VARIOUS FUELS

(A. S. M. E. Boiler Code)

Fuel	Heating Value	
	B. t. u. per Pound	B. t. u. per Cubic Foot
Semi-bituminous coal	14,500	
Anthracite	13,700	
Screenings	12,500	
Coke	13,500	
Wood, hard or soft, kiln-dried	7,700	
Wood, hard or soft, air-dried	6,200	
Wood shavings	6,400	
Peat, air-dried, 25 per cent. moisture	7,500	
Lignite	10,000	
Kerosene	20,000	
Petroleum, crude oil, Pennsylvania	20,700	
Petroleum, crude oil, Texas	18,500	
Natural gas		960
Blast-furnace gas		100
Producer gas		150
Water gas, uncarbureted		290

the greatest amount of fuel that can be burned per hour, and the heating value H of the fuel may be found from Table I.

20. After the value of W, the weight of steam generated per hour, has been found by the formula of the preceding article, the size of safety valve required may be determined by use of Table II. The table gives the discharge capacities of safety valves from ½ inch to 8 inches in diameter at pressures ranging from 15 to 250 pounds per square inch, gauge.

EXAMPLE 1.—The amount of fuel burned under a boiler during the period of maximum forcing is 1,140 pounds of semi-bituminous coal per hour. If the boiler pressure, as shown by the steam gauge, is 125 pounds per square inch, find the size of safety valve required.

TABLE II

MINIMUM SIZES OF BOILER OUTLETS FOR SAFETY VALVES FROM FIRE-TUBE BOILERS FOR VARIOUS DISCHARGE CAPACITIES

Gauge Pressure	Nominal Pipe Size of Boiler Outlet for Safety Valve Connection, in Inches														
Pounds per Square Inch	½	¾	1	1¼	1½	2	2½	3	3½	4	4½	5	6	7	8
	Discharge of Steam per Outlet per Hour, in Pounds														
15	49	74	131	163	245	391	486	782	1,026	1,303	1,613	2,052	2,916	3,909	5,212
25	66	99	174	218	326	523	653	1,046	1,372	1,742	2,156	2,744	3,898	5,226	6,968
50	107	161	284	354	532	851	1,064	1,703	2,235	2,839	3,513	4,470	6,352	8,517	11,356
75	148	198	393	492	738	1,181	1,475	2,361	3,099	3,935	4,870	6,198	8,805	11,805	
100	189	285	503	629	944	1,510	1,877	3,019	3,963	5,032	6,227	7,926	11,259		
125	230	346	613	767	1,149	1,836	2,299	3,677	4,826	6,128	7,583	9,652	13,711		
150	272	408	723	904	1,355	2,158	2,710	4,335	5,690	7,226	8,940	11,380			
175	313	470	835	1,040	1,561	2,497	3,121	4,993	6,553	8,320	10,298	13,106			
200	354	533	941	1,178	1,766	2,826	3,532	5,651	7,418	9,420	11,655	14,836			
225	395	593	1,052	1,315	1,972	3,154	3,944	6,310	8,280	10,514	13,013				
250	437	656	1,161	1,451	2,177	3,484	4,355	6,968	9,143	11,614	14,366				

SOLUTION.—Apply the formula of Art. **19**. From Table I, $H=14{,}500$ B. t. u.; and $C=1{,}140$ lb. Then,

$$W=\frac{.75\times 1{,}140\times 14{,}500}{1{,}100}=11{,}270 \text{ lb. per hr.}$$

On referring to Table II, it is discovered that, at a pressure of 125 lb. per sq. in., the largest size of valve, 6 in. in diameter, has a discharge capacity of 13,711 lb. per hr., but, two valves should be used on a boiler. A 4-in. valve will discharge 6,128 lb. per hr. at 125 lb. per sq. in., and two such valves will discharge 12,256 lb. per hr., which is slightly more than the value of W. Hence, two 4-in. valves will be used. Ans.

EXAMPLE 2.—A boiler carrying 250 pounds pressure burns 1,000 pounds of Pennsylvania crude oil per hour when forced to its maximum. What size of safety valve is required?

SOLUTION.—Apply the formula of Art. **19**. From Table I, $H=20{,}700$ B. t. u. for Pennsylvania crude oil; and $C=1{,}000$ lb. Then,

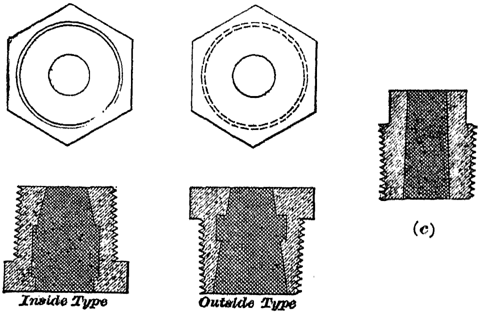
$$W=\frac{.75\times 1{,}000\times 20{,}700}{1{,}100}=14{,}114 \text{ lb. per hr.}$$

Table II shows that two $3\frac{1}{2}$-in. valves will furnish the necessary capacity. Ans.

FUSIBLE PLUGS

21. Purpose of Fusible Plugs.—A fusible plug is a device that is screwed into the crown sheet, tube-sheet, or water leg of a boiler to protect the boiler in case of low water. It consists of a brass or bronze shell cored out and filled with pure tin, which has a melting point a trifle higher than the temperature of the water in the boiler. As long as the plug is covered with water, it transmits the heat to the water rapidly. When the crown sheet or other boiler surface into which it is screwed is exposed directly to the heat without being covered with water, the fusible part of the plug melts quickly, and steam and water are blown through the cored opening of the plug, thus giving warning of low water. The reliability of the plug depends on the melting or fusing temperature of the tin filling at the time it should operate. The presence of relatively small amounts of impurities in the filling may cause a change in its composition and possibly render it useless. Correct methods of manufacture and the use of the best grade of filling material are the means of insuring reliable plugs.

22. Inside and Outside Fusible Plugs.—The inside type of fusible plug, shown in Fig. 8 (*a*), is screwed into the boiler plate from the water side. The hexagonal head of the plug in (*a*) makes a strong construction and enables the plug to be screwed into place. The outside type, shown in (*b*) and (*c*), is screwed into the boiler plate from the outside. Plugs are made in standard sizes from $\frac{3}{8}$ inch to $1\frac{1}{2}$ inches; they are also made with oversize and extra oversize threads, to take care of carelessly tapped holes and holes that have been retapped.



(*a*) (*b*) (*c*)

FIG. 8

A form of plug especially adapted to internally fired boilers of the locomotive type is shown in Fig. 9. The plug *a* is screwed into the crown sheet *b*, and the fusible cap *c* is laid on top of it and kept in place by the nut *d*. A very thin copper cup *e* is placed over the top of the cap *c* to protect it from any chemical action of the water. The top of the cap extends from $1\frac{1}{2}$ to 2 inches above the crown sheet, so that when it melts on account of low water, there will still be enough water left to protect the sheet from being overheated, or *burned*, as it is often termed.

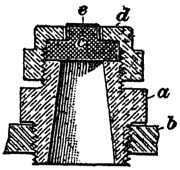


FIG. 9

23. Rules for Use of Fusible Plugs.—Although the advisability of using fusible plugs in boilers subjected to continuous overloads is questioned, the requirements of the American Society of Mechanical Engineers with regard to fusible plugs are as follows: Fusible plugs, if used, shall be filled with tin with a melting point between 400° and 500° F.

and shall be renewed once each year. The least diameter of fusible metal shall be not less than $\frac{1}{2}$ inch, except for maximum allowable working pressures of over 175 pounds per square inch, or when it is necessary to place a fusible plug in a tube, in which case the least diameter of the fusible metal shall be not less than $\frac{3}{8}$ inch.

The use of fusible plugs is not advisable in boilers that are to be operated at working pressures exceeding 225 pounds per square inch. If a fusible plug is inserted in a tube, the tube wall must be not less than .22 inch thick, or thick enough to give four threads.

24. Location of Fusible Plugs.—In horizontal return-tubular boilers, the plug is usually placed in the back head, not less than 2 inches above the top row of tubes, measuring from the top of the tube to the center of the plug. In firebox boilers of the locomotive type, the plug is screwed into the highest point of the crown sheet. In Scotch boilers, the plug is screwed into the top plate of the combustion chamber. In vertical fire-tube boilers, the plug is screwed into one of the outside tubes, and arranged so that it is at least one-third the length of the tube above the lower tube-sheet. In water-tube boilers of the Heine type, it is screwed into the shell of the steam drum, not less than 6 inches above the bottom of the drum. In general, the plug should be so located that it will be in the path of the hot gases and arranged so that it is at the highest point of the boiler, where low water would first become evident.

WATER-LEVEL INDICATORS

25. High- and Low-Water Alarms.—It is important to maintain proper water level in a boiler, so as to safeguard life and valuable equipment, as well as to insure economy in the burning of fuel. Low water may mean burned-out tubes, or crown sheets, which might lead to boiler explosions. An excessively high water level may cause priming, and flood the steam line leading to the pumps, engines, or turbines, so that damage will result to this equipment.

26. A device is often attached to the boiler to give an audible warning, usually by blowing a whistle, of a shortage or a surplus of water. Devices that indicate a shortage of water are called *low-water alarms;* those that indicate either a surplus or a shortage of water are called *high- and low-water alarms.*

In low-water alarms, the whistle may be sounded by the melting of a fusible plug, which, through the falling of the water level in a separate chamber outside of the boiler, is brought in contact with the steam. Fusible-plug alarms are cheap and easily applied; they are rather unreliable, however, because they are liable to become incrusted with scale.

The usual form of low-water alarm employs a float operating a valve leading to a steam whistle, the float being buoyed up by the water. It is like the high- and low-water alarm.

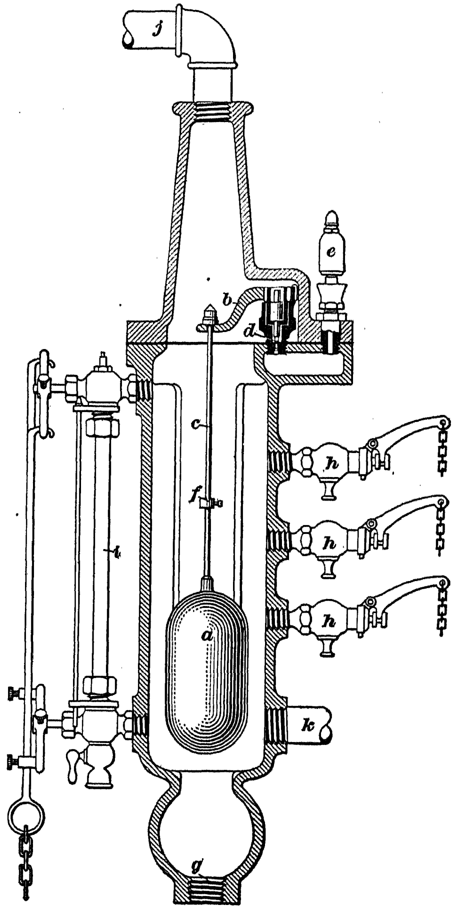


FIG. 10

27. One form of high- and low-water alarm is illustrated in Fig. 10. It consists of a hollow air-tight float a, suspended from a lever b. Within the body of the water column are guides that prevent the float from binding or sticking. When the

water falls in the column to a low level, the weight of the float *a*, acting through the vertical stem *c*, pulls the lever *b* down and thus opens the valve *d*, allowing steam to pass and sound the whistle *e*. When the water level rises sufficiently the float rises until the stop *f* engages the lever *b*, pushing it up. As this lever is double-acting, it operates the valve *d* by either an upward or a downward motion. The stop *f* is adjustable and can be set in any desired position on the rod *c*. The proper action of the signal can be tested by opening the drain valve attached at *g*, which will drain the water and allow the float to fall and sound the whistle. Gauge-cocks *h* and a gauge glass *i* are connected to the body of the water column, as shown. The device is connected at *j* with the steam space of the boiler and at *k* with the water space.

28. Gauge-Cocks.—A gauge-cock is a simple cock or valve attached either directly to the boiler, or, preferably, to a water column, for the purpose of testing the level of the water in the boiler. Three gauge-cocks are generally employed. The lowest is placed at the lowest level that the water may safely attain, and the uppermost at the highest desirable level. The third cock is placed midway between the other two. On opening a cock above the water level, steam will issue forth, and on opening one below the water level, water will appear. Hence, the level may be easily located by opening the cocks in succession.

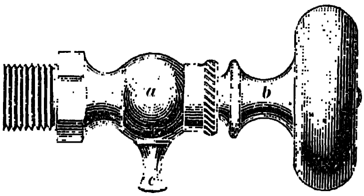


FIG. 11

29. The gauge-cock most commonly used is of the compression type. Such a cock, with a wooden hand wheel, is shown in Fig. 11. It consists of a brass body *a* having a threaded shank for attaching it to the boiler or water column. The seat within the body is closed by the end of the threaded valve stem *b*. The steam or water issues from the nozzle *c* when the cock is opened. Compression gauge-cocks can be obtained with a lever handle in the form of a crank. Such

cocks can be operated from a distance by means of a rod. In some designs the valve is held to its seat by a strong spring, which automatically closes the valve the moment the hand releases it.

30. A weighted gauge-cock, known to the trade as a *Register pattern cock*, is shown in Fig. 12. It consists of a body *a* having a threaded shank for attaching it to the boiler or the water column. The weight *b* is pivoted at *c* to the body, and when down presses a strip *d* of soft-rubber packing against the face of the opening at *e*. The cock is opened by lifting the weight slightly, and the issuing steam or water is deflected downwards by the curved end wall of the slot. In order to show the construction clearly, the weight is shown raised to the full limit. The strip of soft-rubber packing is simply pushed through two opposite slots. It must be renewed frequently, as it rots under the high temperature to which it is subjected in service.

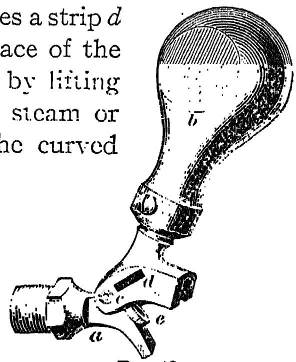


FIG. 12

31. Glass Water Gauges.—The gauge glass is a glass tube whose lower end communicates with the water space of the boiler and whose upper end is in communication with the steam space; hence, the level of the water in the gauge glass should be the same as in the boiler. Fig. 13 shows a common method of connecting a gauge glass *a*. The lower fitting *b* opens into the water space, and the upper fitting *c* into the steam space of the boiler. A drip cock *d* is placed at the lower end of the glass for the purpose of draining it. Two brass rods *e* tend to protect the gauge glass against accidental breakage. The fittings may be screwed directly into the boiler. The gauge should be so located that the water will show in the middle of the gauge glass when at its proper level in the boiler. Both fittings have cocks *f* by means of which communication with the boiler can be shut off and the escape of steam and water prevented in case the gauge glass breaks.

32. Automatic Safety Water Gauges.—To prevent loss of steam and water, and to obviate the danger of scalding the workman who tries to close the valves, it is desirable to have water gauges that will automatically shut off communication with the boiler whenever the gauge glass breaks. There

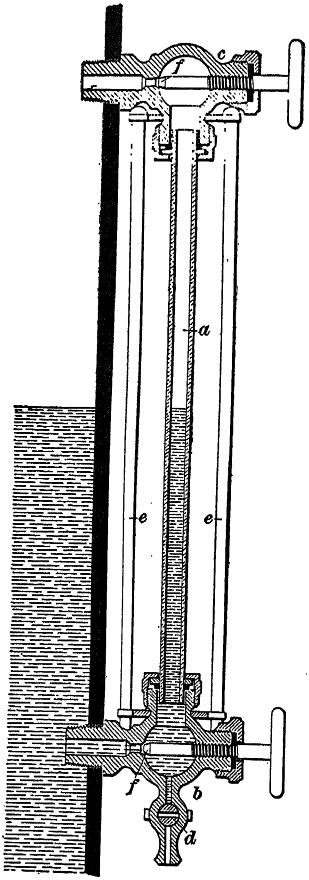
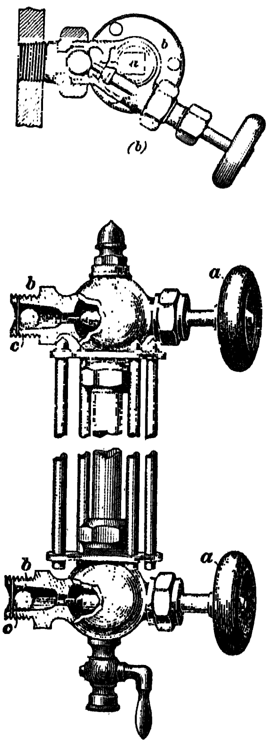


FIG. 13



(a)

FIG. 14

are many designs of such valves on the market. Fig. 14 (*a*) is a typical automatic pattern with hand-control valves *a*. A ball *b* is placed within the shank of each fitting, and is prevented from falling out by a brass pin *c*. Should the gauge

glass break, the outward rush of steam and water will carry the balls forward and thus close the openings leading to the gauge glass. The balls close the gauge-glass openings sufficiently to permit the hand valves *a* to be closed without danger of scalding the boiler attendant. The shut-off valve at the top of the gauge-glass fitting may be offset, as shown in the

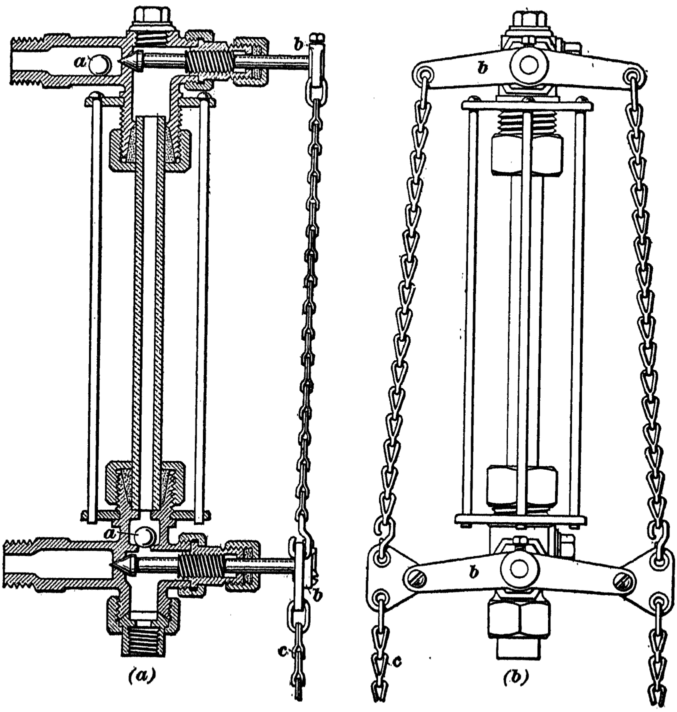


Fig. 15

plan view (*b*), so as to enable the glass to be inserted or removed easily. A plug *a* is screwed into the fitting *b* directly over the gauge glass. When this plug is removed and the packing nuts on the glass have been loosened, the glass may be pushed straight up through the top fitting.

To avoid entirely the danger of scalding the hands, the lever type of safety water gauge, with automatic ball control,

as shown in Fig. 15 (*a*) and (*b*), may be used. The balls are arranged as shown at *a* in the cross-sectional view (*a*) and work on the same principle as in Fig. 14, in case of glass breakage. The levers *b*, Fig. 15, are operated by chains *c* and the valves are closed and opened by pulling the chains.

33. Water Column.—A common form of water column is shown in Fig. 16. It consists of a hexagonal cast-iron standpipe *a* tapped at the top and the bottom for pipe connections to the boiler. Tapped bosses are provided, which receive the threaded shanks of the gauge-glass fittings *b* and the gauge-cocks *c*. Each maker has his own style of standpipe, the different makes varying chiefly in the ornamentation. The steam gauge is frequently mounted on top of the water column.

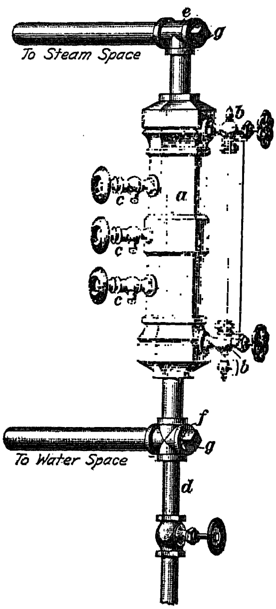


Fig. 16

In certain States, it is not allowable to place valves in the piping between the water column and the boiler, because of the danger that such valves may be closed and thus cause incorrect indication of the water level, with the possibility of serious consequences. Yet it is convenient to have shut-off valves, to avoid the necessity of closing down the boiler in case of accident to the water column. If such valves are installed, the fireman should make sure that they are fully open when the boiler is in operation. The pipe connections to the water column should not be less than $1\frac{1}{4}$ inches in diameter.

34. Water-Column Connections.—The connection to the boiler should be made with a **T** on the top, as at *e*, Fig. 16, and a cross *f* on the bottom, with the unused openings plugged with brass plugs *g*. If the connections are made in this manner,

they can be cleaned with a rod when the plugs are unscrewed. A drain pipe *d* with a valve in it, and leading to the ash-pit, should always be provided for the standpipe, and should be frequently used for blowing out sediment collecting in the standpipe. For low-pressure boilers no valves need be placed in the pipes leading to the steam and water spaces of the boiler; for high-pressure boilers, however, valves should always be provided. These valves are used in blowing out the standpipe and connections. Closing the valve in the upper pipe and opening the valve in the drain pipe blows out the lower pipe; closing the valve in the lower pipe and opening the valve in the drain pipe blows out the upper pipe and the standpipe.

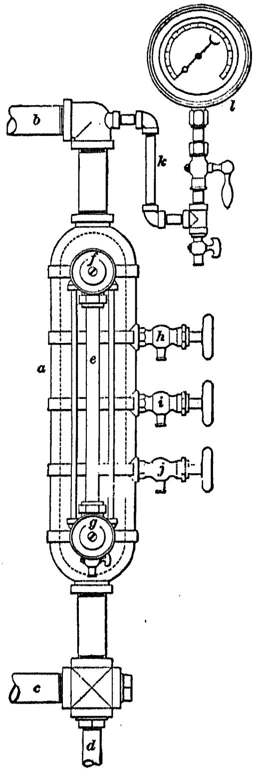


Fig. 17

35. An arrangement of water column, gauge glass, gauge-cocks, and steam gauge recommended by the Hartford Boiler Insurance Company is shown in Fig. 17. The round cast-iron column *a* has an inside diameter of about 4 inches. The upper end communicates with the steam space of the boiler by means of the pipe connection *b*, and the lower end with the water space through the pipe connection *c*. A drip pipe *d* is used for removing the water from the column occasionally in order to prevent it from becoming clogged. The gauge glass *e* communicates with the column through the connections *f* and *g*. The gauge-cocks *h*, *i*, and *j* are attached to the water column; a siphon *k* protects the steam gauge *l*.

36. Installation of Gauge Glasses, Gauge-Cocks, and Water Columns.—The Boiler Code of the American Society of Mechanical Engineers specifies the following requirements

for the installation of gauge glasses, gauge-cocks, and water columns:

Each boiler shall have at least one water-gauge glass, the lowest visible part of which shall be not less than 2 inches above the lowest permissible water level. The lowest permissible water level for various classes of boilers shall be the location for the fusible plug.

Automatic shut-off valves on water gauges, if permitted to be used, shall conform to the following requirements:

(*a*) Check-valves in upper and lower fittings must be of the solid non-ferrous ball type to avoid corrosion and the necessity for guides.

(*b*) Ball check-valves in upper and lower fittings must open by gravity, and the lower check-valve must rise vertically to its seat.

(*c*) The check balls must not be smaller than $\frac{1}{2}$ inch in diameter, and the diameter of the circle of contact with the seat must not be greater than two-thirds of the diameter of the check ball. The space around each ball must not be less than $\frac{1}{8}$ inch, and the travel movement from the normal resting place to the seat must not be less than $\frac{1}{4}$ inch.

(*d*) The ball seat in the upper fitting must be a flat seat with either a square or a hexagonal opening, or otherwise arranged so that the steam passage can never be completely closed by this valve.

(*e*) The shut-off valve in the upper fitting must have a projection which holds the ball at least $\frac{1}{4}$ inch away from its seat when the shut-off valve is closed.

(*f*) The balls must be accessible for inspection. Means must be provided for removal and inspection of the lower ball check-valve, while the boiler is under steam pressure.

When shut-offs are used on the connections to a water column, they shall be either outside-screw and yoke-type gate valves or stop-cocks with levers permanently fastened thereto and marked in line with their passage, and such valves or cocks shall be locked or sealed open.

Each boiler shall have three or more gauge-cocks, located within the range of the visible length of the water glass, except when such boiler has two water glasses with independent connections to the boiler and located on the same horizontal line and not less than 2 feet apart.

No outlet connections, except for damper regulator, feed-water regulator, drains, or steam gauges, shall be placed on the pipes connecting a water column to a boiler.

PRESSURE GAUGES

37. Steam Gauge.—The steam gauge, the face *a* of which is shown in Fig. 18, indicates the pressure of the steam contained in the boiler. The most common form is the *Bourdon pressure gauge*, the distinguishing feature of which is a bent elliptical

tube that tends to straighten out under an internal pressure. Bourdon pressure gauges are made in various ways by different manufacturers; a very common design is shown in Fig. 19. It consists of a two-branched bent tube *a*, of elliptical cross-section, that is filled with water and connected at *b* with a pipe leading to the boiler. The two ends *c* are closed and are are attached to a link *d*, which is, in turn, connected with a quadrant *e*; this quadrant gears with a pinion *f* on the axis of the index or pointer *g*.

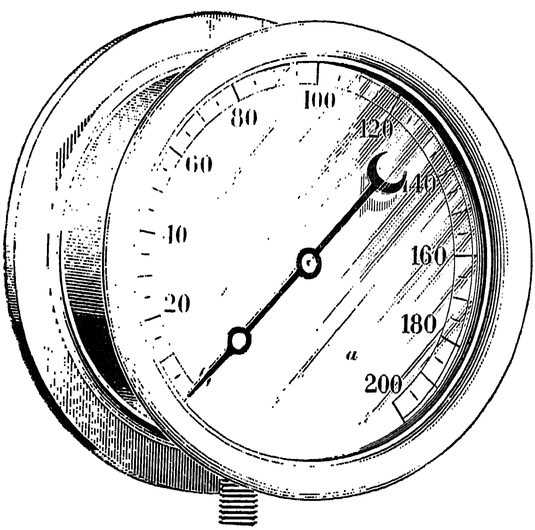


FIG. 18

38. When the water contained in the elliptical tube *a*, Fig. 19, is subjected to pressure, the tube tends to take a circular form, and, as a whole, straightens out, throwing out the free ends to a distance proportional to the pressure. The movement of the free ends is transmitted to the pointer by the link, quadrant, and pinion, and the pressure is thus recorded on a graduated dial in front. The illustration shows the gauge with the dial removed in order to display the mechanism. This type is especially adapted for stationary, marine, and portable boilers subjected to a great deal of vibration.

The single-tube steam gauge, shown in Fig. 20, consists of a tube *a*, the free end of which is connected to a lever *b* attached to a toothed sector *c* that moves a small pinion on the pointer shaft *d*. Lost motion is prevented by the action of a small hair-spring *e*, which is also used in steam gauges of the double-tube type.

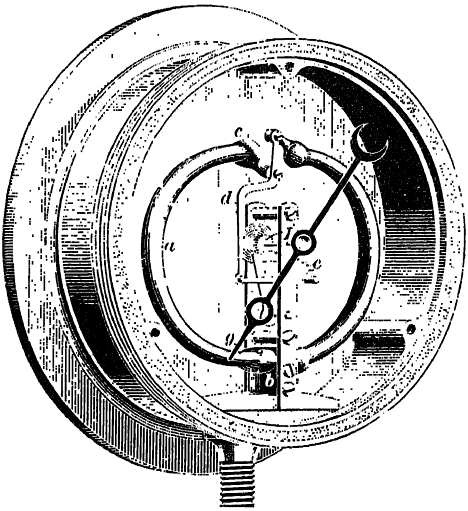


FIG. 19

Pressure gauges for indicating steam pressure are graduated to show the pressure above that of the atmosphere, in pounds per square inch, wherever the English system of weights and measures is used.

39. Steam-Gauge Siphons.—A steam gauge must be connected to the boiler in such a manner that it will not be injured by heat nor indicate the pressure incorrectly. To prevent injury from the heat of the steam, a siphon may be used to connect the steam gauge to the steam space of the boiler. The siphon may be arranged as shown in Fig. 21 (*a*) and (*b*), or as in Fig. 22. Within a short time after the steam gauge is

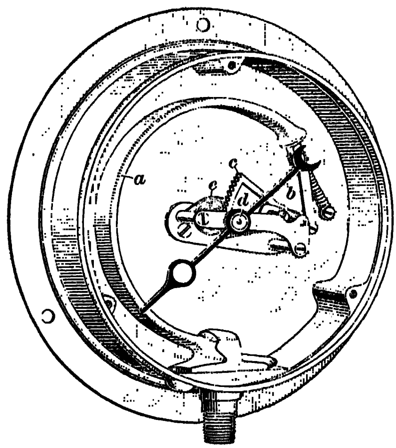


FIG. 20

put into use, the siphon becomes filled with water formed by the condensation of steam. The water protects the tube of the gauge from injury that would result if the hot steam had free circulation in the tube. Temperatures above 150° F. may affect the elasticity of the tube and thus impair the accuracy of the gauge. The steam-gauge pipe should not be connected to the main steam pipe leading from the boiler, nor should it be located near the outlet of that pipe, as this may cause the gauge to indicate a lower pressure than really exists in the boiler. The gauge should be connected to the siphon as

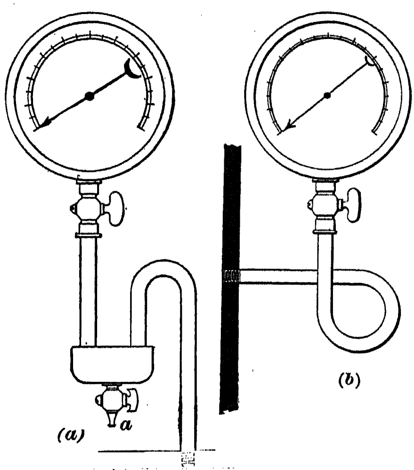


FIG. 21

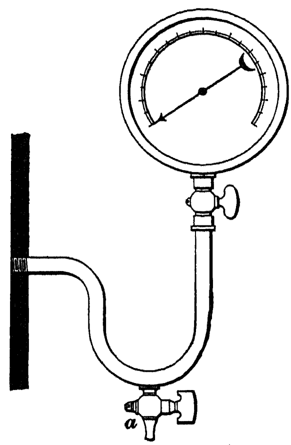


FIG. 22

indicated in the illustrations so that the water which accumulates in the siphon does not act to increase the pressure.

The siphons shown in Fig. 21 cannot be drained without disconnecting them from the boiler. To overcome this disadvantage, a petcock, as shown at *a*, Figs. 21 (*a*) and 22, may be placed at the lowest point of the siphon. The petcock should not be opened while the steam gauge is in service, as then the water seal would be lost and the tube would be damaged by the steam.

40. Testing Steam Gauges.—A steam gauge will lose its accuracy after it has been in use for some time, owing to the

fact that the tube loses its elasticity and takes a permanent set. In this case the gauge will indicate a pressure higher than the actual pressure in the boiler. This can usually be discovered by the failure of the pointer to return to the zero mark when there is no pressure in the boiler. If the pressure apparently indicated when there is no pressure is subtracted from the pressure indicated when the boiler is under steam, the correct pressure will be given approximately. However, when a gauge shows a wrong pressure, a new one should be immediately substituted and the old one discarded or sent to the maker for repair.

When inspecting boilers, the inspectors of boiler-insurance companies or municipal boiler inspectors usually test all steam gauges in the plant by comparison with an accurate test gauge. The gauge to be tested and the test gauge are both attached to a vessel in which the pressure is raised by means of a small force pump, and the readings of the two gauges at different pressures are compared.

41. The safety valve can be checked by means of the steam gauge when the latter is known to be accurate. Conversely, when the safety valve is known to be set correctly, the steam gauge can be checked for the blow-off pressure by watching its indication when the valve just blows off. If a steam gauge shows an error of more than 5 pounds, it will be condemned by most boiler inspectors. The steam gauge should be taken off periodically and the connecting pipe cleared by blowing steam through it. When the gauge is off, care should be taken to see that the hole in the nipple is perfectly clear.

Good practice demands that a steam gauge should be attached to each boiler, when more than one boiler is used. In some regions, however, it is not uncommon to see one steam gauge do duty for a whole battery of boilers. Such an arrangement has nothing but cheapness to recommend it and is severely condemned by engineers and insurance companies.

42. When the boiler supplies steam to a steam engine, it sometimes happens that, when the engine is running, the pointer of the steam gauge vibrates so much that the pressure

cannot be read. This can be prevented by partly closing the petcock shown below the gauges in Figs. 21 and 22. The greatest care must be taken, however, to prevent entire closing of the cock. The pointer of a steam gauge will stick occasionally; hence, experienced engineers always jar the gauge a little, in order to dislodge anything that may be preventing movement of the pointer, before they accept its indication as correct.

43. The spring tube of a steam gauge is liable to corrode when certain kinds of water are used. Under no circumstances should an attempt be made to fix a corroded tube by soldering up the hole or holes; instead, the gauge should be sent to the maker to have a new tube fitted and adjusted. When a gauge has been taken off, it should not be replaced without making sure that the passage through the cock on the steam-gauge pipe is clear when the cock is in the open position. Care should also be taken to see that the gauge is free to operate after it has been replaced. It has happened that, when the piping was being put up, the gasket placed between the two parts of the union was so large that in tightening the nut it was squeezed out so as to stop the hole in the pipe completely, thus preventing the gauge from showing the pressure.

44. Rules for Installation and Use of Steam Gauges.—The rules given by the A. S. M. E. Boiler Code for the installation of steam gauges are as follows:

Each boiler shall have a steam gauge connected to the steam space or to the water column or its steam connection. The steam gauge shall be connected to a siphon or equivalent device of sufficient capacity to keep the gauge tube filled with water and so arranged that the gauge cannot be shut off from the boiler except by a cock placed near the gauge and provided with a tee or lever handle arranged to be parallel to the pipe in which it is located when the cock is open. Connections to gauges shall be of copper, brass, or bronze composition.

Where the use of a long pipe becomes necessary, an exception may be made to the rule that the gauge must be arranged so that it cannot be shut off except by a cock placed near the gauge, and a shut-off valve or cock arranged so that it can be locked or sealed open may be used near the boiler. Such a pipe shall be of ample size and arranged so that it may be cleared by blowing out.

The dial of the steam gauge shall be graduated to approximately double the pressure at which the boiler will operate, but in no case to less than $1\frac{1}{2}$ times the maximum allowable working pressure on the boiler.

Each boiler shall be provided with a $\frac{1}{4}$-inch pipe size valved connection for the exclusive purpose of attaching a test gauge when the boiler is in service, so that the accuracy of the boiler steam gauge can be ascertained.

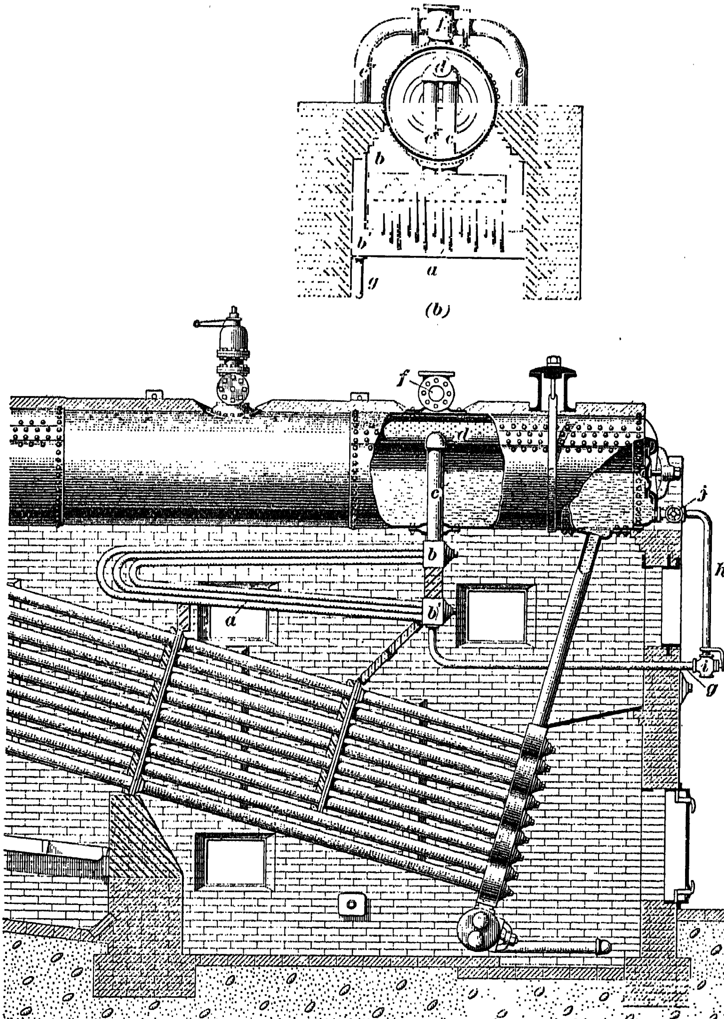
SUPERHEATERS

45. Purpose of Superheating.—Steam in contact with the water in a boiler has the same temperature as the water and is known as saturated steam. Additional water may be taken up by the steam through priming of the boiler or from the movement of the boiler, as in marine, portable, and locomotive boilers. Moisture also arises from condensation of the steam. Large heat losses result from the use of wet steam for power purposes, and there are other disadvantages in the effect of such steam on turbines, engines, etc. In turbines, water in the rapidly moving steam erodes, or wears away, the blades, and increases the amount of steam used. The same conditions arise in reciprocating engines, and there is a possibility of damaging the cylinder heads and the stuffingboxes around piston rods and valve stems.

46. The demand for greater economy in the performance of steam engines has led to the development of the superheater, by means of which the steam may be superheated to a moderate degree so that it will contain more heat and therefore do more work than would the same weight of saturated steam, and thus insure increased engine economy. In order to superheat the steam, it must pass from the boiler into a separate compartment and have more heat applied to it. This may be done with a separate furnace or by using a coil of pipe within the boiler setting itself; or, the superheater may be arranged in the smokebox of a locomotive boiler, or in the uptake leading to the stack in other boiler installations.

47. Wrought-Iron Superheater.—One form of superheater, as arranged in connection with a water-tube boiler, is shown in Fig. 23 (*a*) and (*b*). It consists of a number of bent wrought-

iron tubes a with their ends expanded into headers b, b', and is located in the upper part of the combustion chamber of



(b)

(a)

Fig. 23

the boiler. The upper header b is connected with the dry pipe d by two vertical pipes c, c', while the lower header b' is con-

nected by means of two pipes *e*, *e*′, to the steam outlet *f* on top of the boiler. The steam is drawn from the dry pipe through the pipes *c*, *c*′ to the upper header *b*, thence through the superheater tubes *a* to the lower header *b*′, and up the external pipes *e*, *e*′, to the steam outlet *f*. The lower header *b*′ is connected to the water space of the boiler by means of the pipes *g* and *h*, fitted with valves *i* and *j* for the purpose of filling the superheater with water when not in use, as is the case when getting up steam or when the engine is not running. To put

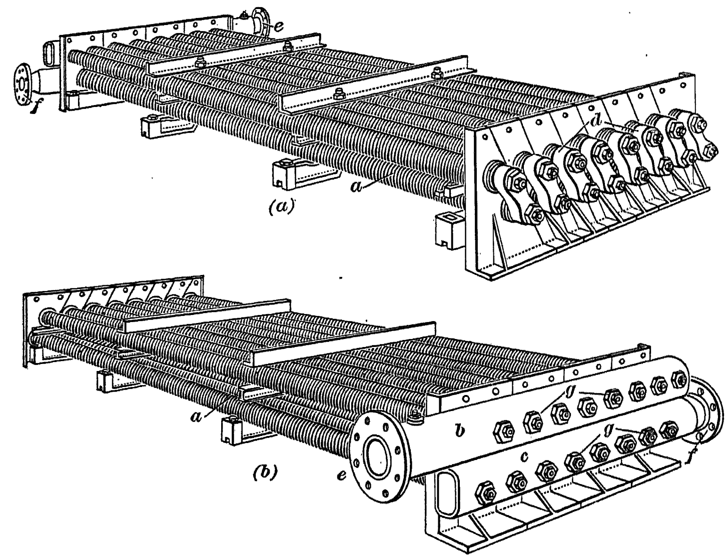


FIG. 24

the superheater into service, the water is drained from it by means of the three-way valve *i*. Not all superheaters have provision made for flooding while steam is being raised. In many cases a valve on the superheater is opened, allowing air and steam to escape from the superheater until full pressure on the boiler is reached, when the valve is closed and the superheater is cut into service.

48. Foster Superheater.—The Foster superheater, two views of which are shown in Fig. 24 (*a*) and (*b*), consists of a

series of straight seamless steel tubes, over which are slipped a large number of cast-iron rings *a*; these cover the tubes with cast-iron fins that absorb the heat and conduct it to the tubes. At the same time, the cast-iron rings prevent the tubes from burning out and protect them from the corrosive action of the furnace gases. The steel tubes are expanded into the headers *b* and *c* and at the other end are joined by the tube fittings *d*. Steam enters the header *b* at *e*, flows through the upper bank of tubes, down through the fittings *d*, back through the lower bank of tubes into the header *c*, and out at *f*. Handholes *g* are provided in the headers *b* and *c* and in the fittings *d* opposite the tubes. A cross-section through one of the handhole plugs is shown in Fig. 25. The plug *a* is tapered and is in one piece with the stud *b*. A copper gasket *c* is inserted between the plug and the tapered seat, the yoke *d* is set over the stud, and the plug is drawn to its seat by the nut *e*. The form of superheater shown in Fig. 24 is so arranged in the boiler setting that the headers *b* and *c* and the fittings *d* are accessible from the outside of the boiler, thus making it easy to remove the handhole plugs for cleaning, inspecting, or repairing the superheater.

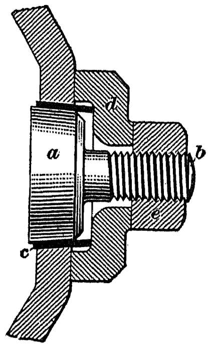


FIG. 25

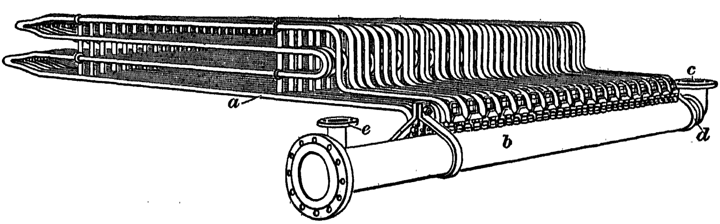


FIG. 26

49. Elesco Superheater.—A form of superheater for stationary boilers is shown in Fig. 26. It consists of a large number of cold-drawn seamless steel tubes *a* attached to two headers *b* and *c*. The tubes are bent, as shown, so as to provide

a large amount of surface to be exposed to the hot gases, and at the same time to take care of the expansion and contraction. Saturated steam from the boiler enters the header *b*, which is closed at the end *d*, and flows through the banks of piping *a*, wherein it is superheated. It then passes out of the tubes *a* into the header *c*, which lies behind the header *b*, and which is also closed at one end. The flange *e* on the header *b* forms a connection for the installation of the safety valve.

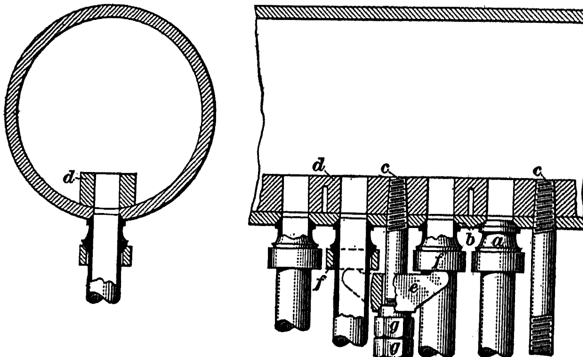


FIG. 27

50. The ends of the tubes are connected to the headers by metal-to-metal joints, as shown in the sectional view, Fig. 27. The end *a* of each tube is formed by a special forging process and is then ground to an angle of 45° to fit the conical seat in the header, as shown at *b*. Between each pair of tubes is a stud *c* that passes through the wall of the header into a reinforcing strip *d*. A two-armed clamp *e* is slipped over the stud, and its ends bear against the collars *f* on the tubes. When the clamp is forced against the collars by screwing up the nuts *g* on the stud, the ends of the tubes are held tightly in the conical seats in the header. This construction enables the tubes to be removed or replaced with little labor or loss of time.

BOILER DETAILS
(PART 1)

FIRE-TUBE AND WATER-TUBE BOILER DETAILS

RIVETED JOINTS

RIVETS AND RIVETING

1. Forms of Rivets.—The plates that form steam boilers are fastened together by rivets. A rivet is a piece of soft iron or steel rod with a head formed at one end. The cylindrical part of the rivet is called the *shank;* it is inserted into a hole drilled or punched through the plates to be joined, and its end is then hammered or pressed to form a second head, the plates being gripped and held firmly between the heads. The most common forms of rivet heads are shown in Fig. 1, and the dimensions are given in terms of the diameter d of the shank. From these dimensions it is easy to calculate the proportions of a rivet head of any type for any diameter of rivet shank. For example, suppose that the dimensions of the head shown in (*a*) are required for a rivet whose shank is $\frac{3}{4}$ inch in diameter. As $d=\frac{3}{4}$ inch, the height of the head is $.75\ d=.75\times.75=.5625$ inch, or $\frac{9}{16}$ inch, and the diameter of the head is $1.75\ d=1.75\times.75=1\frac{5}{16}$ inches.

2. The proportions of rivets shown in Fig. 1 are in accordance with the A. S. M. E. Boiler Code, but a variation of 10 per cent. is permissible; that is, any dimension may be

as much as one-tenth larger or smaller than that indicated. In boiler, plate, and tank work, various forms of rivets are used, and their names are derived from the shapes of their heads. Of the several forms shown in the illustration, those in (*b*),

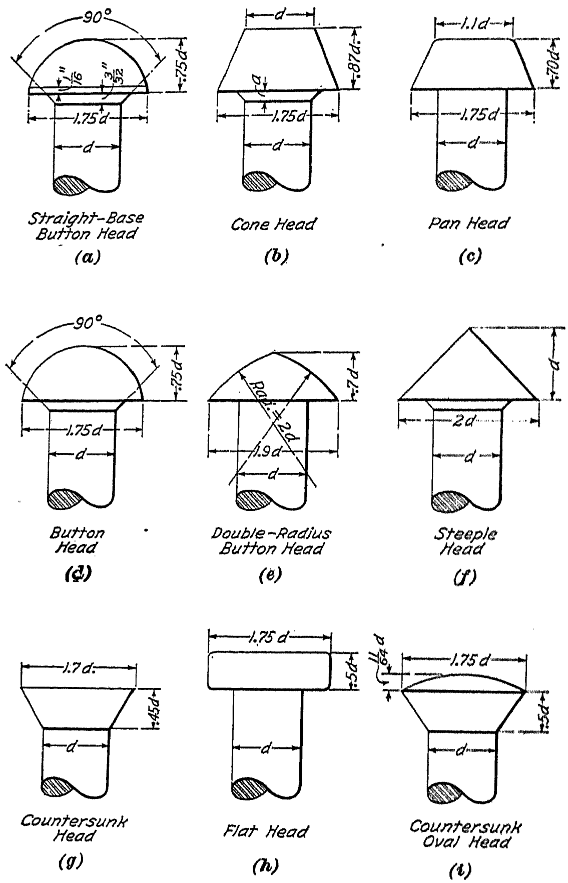
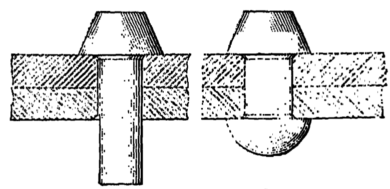


FIG. 1

(*c*), (*d*), (*e*), and (*g*) are most commonly used in boiler construction. The cone-head rivet is slightly tapered under the head, the depth *a* of the tapered part being $\frac{1}{32}$ inch for rivets from $\frac{1}{2}$ inch to 1 inch in diameter and $\frac{1}{16}$ inch for rivets greater than 1 inch in diameter. The outer edge of the rivet

hole is correspondingly beveled, or chamfered, when this form of rivet is used, as shown in Fig. 2 (*a*), thus removing the sharp corner around the hole and making a good seat for the rivet head. Frequently this form of rivet is driven, or headed, by the use of tools that form button heads on both ends, instead of on one end only, as shown in (*b*); it has proved to be a very good form to obtain steam-tight joints.

3. The double-radius button-head rivet, shown in Fig. 1 (*e*), and known also as the conoid-head rivet, is another very good form. In fact, it is generally believed to be superior to the button-head type, as it is easily made tight in the plate and remains so. The countersunk rivet, shown in (*g*), is used in riveted joints when it is undesirable to have rivet heads project above the surface, where they might interfere with the placing of plates or other parts in their correct positions. The flat-head rivet, shown in (*h*), is also used for some connections of the same kind, but is more extensively employed in lighter sheet-metal work, such as breechings, stacks, and boiler casings. The rivet holes in plates are made from $\frac{1}{32}$ to $\frac{1}{16}$ inch larger in diameter than the rivet shank, so that the rivet may be inserted readily.


(*a*) (*b*)
FIG. 2

4. Methods of Riveting.—The act of joining pieces of metal by means of rivets is known as riveting; and it consists of passing a rivet through holes in the metal and then forming a second head. That part of the shank from which a second head is formed is usually known as the *neck* of the rivet. The rivet head may be formed entirely by hammering with a light hammer, in which case the process is called *hand riveting.*

If the head is formed by striking a die with a heavy hammer, the process is called *snap riveting,* which is a modification of hand riveting; the *die,* which is called a *set,* or *snap,* is a piece of hardened steel hollowed out to the desired form of head. If the head is formed by striking comparatively light,

but very rapid blows, with an *air hammer*, or *pneumatic hammer*, the process is called *pneumatic riveting*. If the head is formed by squeezing, or upsetting, the metal of the neck under high pressure in a machine, the process is called *machine riveting;* and if the machine is operated by hydraulic pressure, the process is called *hydraulic riveting*, or *bull riveting*.

5. For boiler work in general, machine riveting has important advantages over hand riveting, and it is now employed wherever possible. The advantages are as follows: (*a*) A tighter joint can be made for the reason that the plates that are being riveted can be held together with greater force while the second rivet head is being formed. (*b*) The holes in the plates can be filled better, because the shank is made to spread out by the pressure applied to upset the rivet and to form the head. (*c*) It is faster and cheaper, if many rivets are to be driven.

FORMS OF RIVETED JOINTS

6. Terms Used in Riveted Work.—If a joint is formed by having the edges of two plates overlapped and joined by one or more rows of rivets, it is called a *lap joint*. If the plates are placed edge to edge and the junction or seam is covered with a narrow strip of boiler plate, called a *strap*, on either one or both sides of the plate, and the whole is riveted together, the joint is called a *butt joint*. The strap is also known as a *cover-plate*, a *welt*, or a *butt strap*. The terms *seam* and *joint* mean the same when applied to riveted connections. Riveted joints are also classified, according to the number of rows of rivets in the seam, as *single-riveted, double-riveted, triple-riveted*, and *quadruple-riveted joints*, and from the arrangement of the rivets in the joint as *staggered-riveted* and *chain-riveted joints*. A single-riveted lap joint is shown in Fig. 3. The distance between rivet centers, measured in the direction

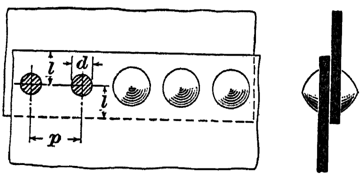
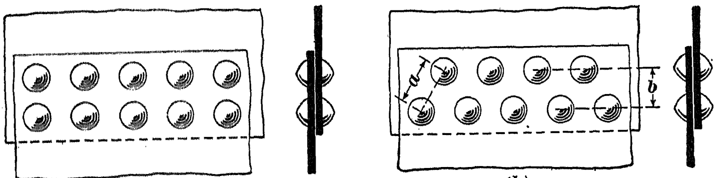


FIG. 3

of the length of the seam, is the *pitch* of the rivets, and the *lap* is the distance l from the center of the rivet hole to the edge of the plate.

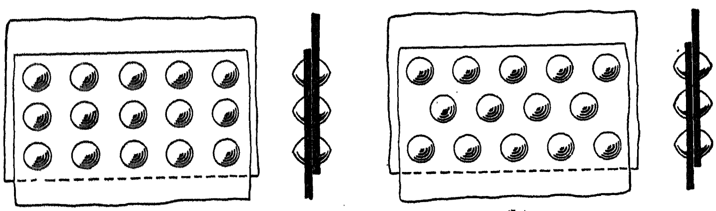
7. Double- and Triple-Riveted Lap Joints.—Two different forms of double-riveted lap joint are shown in Fig. 4, that



(a) (b)

FIG. 4

in (a) being chain-riveted and that in (b) staggered-riveted. In a joint having chain riveting, the rivets in one row are directly opposite those in the next row; but, if staggered riveting is used, the rivets in one row are opposite the centers of the spaces between the rivets in the adjacent row. A joint with staggered riveting is often referred to as a *zigzag-riveted joint.* The diagonal distance a from the center of one rivet to the center of the next rivet in the adjacent row is called the *diagonal pitch.* The distance b between the center lines of adjacent rows of rivets is the *back pitch;* it is measured at right angles to the direction of the seam.



(a) (b)

FIG. 5

Two types of triple-riveted lap joint are shown in Fig. 5, that in (a) having chain riveting and that in (b) staggered riveting. Quadruple-riveted lap joints have four rows of rivets and either chain or staggered riveting may be used.

Triple-riveted and quadruple-riveted lap joints are now seldom used in boiler work. Formerly such joints were used for longitudinal seams, but owing to the offset produced by overlapping the plate, difficulty arose in obtaining a true cylindrical shell. Another objection to such seams is that when the shell is under pressure, a bending action arises in the joint, which produces crystallized metal between the rivets. A correctly designed butt joint is superior to the lap joint in regard to strength and by its use the shell can be rolled to a true cylindrical form.

8. Single-Riveted Single-Strap Butt Joint.—A single-riveted butt joint with a single cover-plate *a* is illustrated in Fig. 6 (*a*) and (*b*). The ends of the boiler shell *b* are butted against each other, and in order to have the edges straight and parallel with each other they are machined on a plate planer. It will be seen that the joint has two rows of rivets *c* and yet is called a single-riveted butt joint. This follows from the fact that the separation of one plate from the other is opposed by only one row of rivets. Thus, if the plate is stronger than the rivets, the plates *b* can be separated only by shearing off the rivets. The pull on the joint, as shown by the arrows in (*a*), tends to break or tear the butt strap along the line *d d*, to crush or shear the metal in front of the rivets, as indicated by the dotted lines *e*, and to shear the rivets as shown at *f* in (*b*). Rivets driven through the plate and the butt strap and acted on by the pressure are in single shear, as the resistance of the rivet to shearing action is that of the sectional area of each rivet. Butt joints with single butt straps may be double-riveted, triple-riveted, etc., and the rivet arrangement may be chain or staggered.

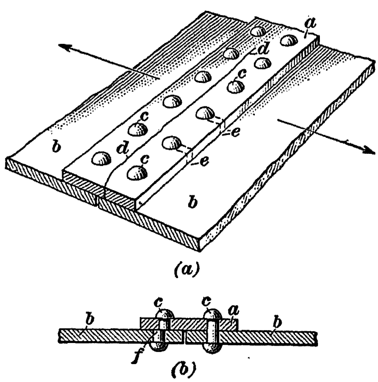


FIG. 6

9. Double-Strap Butt Joints.—The butt joint in Fig. 7 (*a*) consists of plates *a* that butt together at *b* and are joined by the use of two butt straps *c* and *d*. The outer strap *c* is narrower than the inner strap *d*. It will be noticed in the sectional view (*b*) that the outer strap is riveted to the plates and the inner butt strap by two rows of rivets, and that the inner

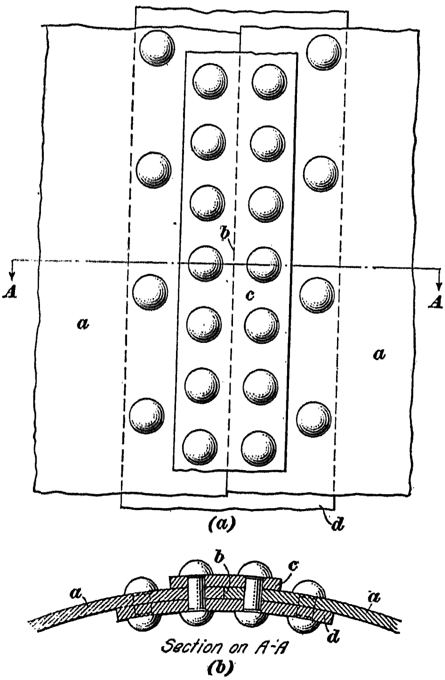


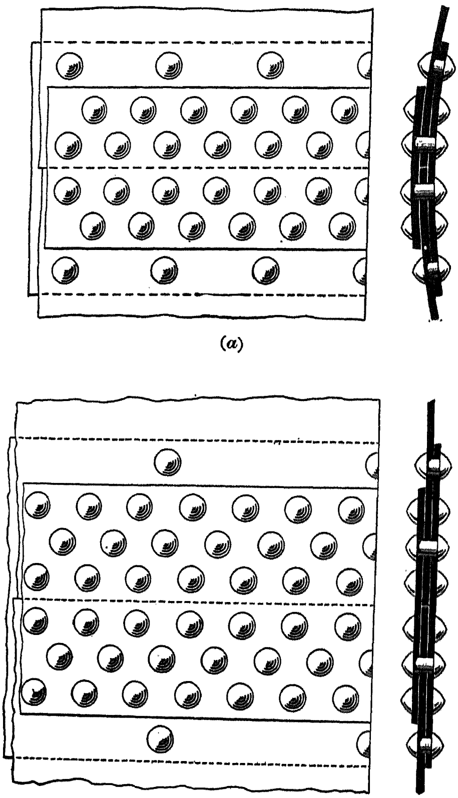
FIG. 7

strap is riveted to the plates by four rows of rivets, two rows being on each side.

Butt joints may also be triple-riveted, as shown in Fig. 8 (*a*), or quadruple-riveted as in (b), with the rivets arranged according to the staggered or the chain method. The chief advantage of the double-strap butt joint having the outer strap narrower than the inner strap is that it may be designed to give a stronger form of joint than any other. The rivets are

usually staggered. The pitch of the rivets in the outer rows, which are in single shear, is double the pitch of the rivets in the inner rows.

10. Butt Joints With Straps of Equal Widths.—A triple-riveted double-strap butt joint with chain riveting is shown in



(*a*)

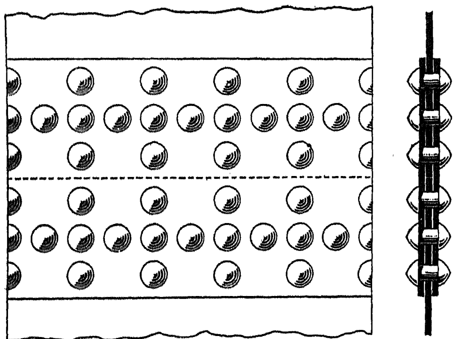
(*b*)

FIG. 8

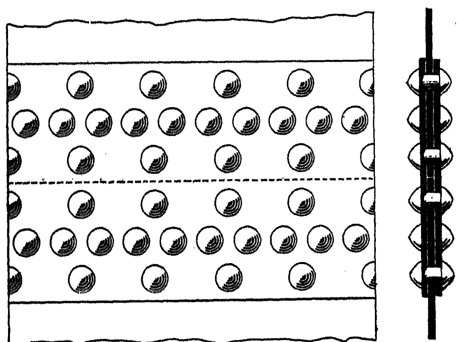
Fig. 9 (*a*) and the same type of joint with staggered riveting in (*b*). The inner and the outer butt straps are of the same width. On each side of the center line of the seam, indicated by the dotted line, there are three rows of rivets. The rivets

in the outer and the inner rows of these three have twice the pitch of the rivets in the center row.

Another form of double-strap butt joint, known as the *saw-tooth joint,* is shown in Fig. 10 (*a*) and (*b*). It is quadruple-riveted, and the outer strap *a* is cut to the outline indicated,



(*a*)

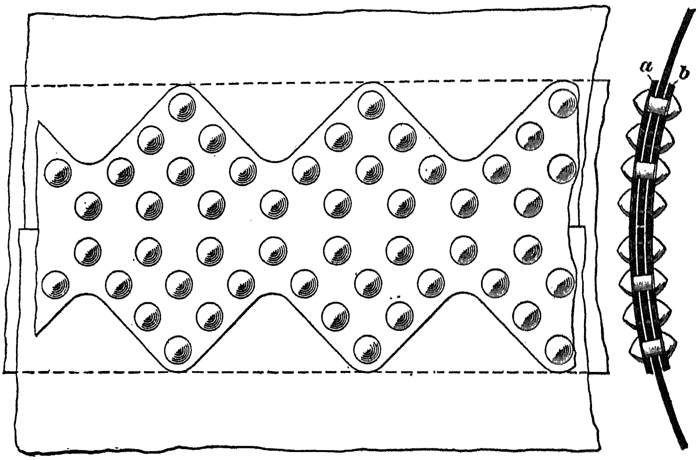


(*b*)

FIG. 9

the joint taking its name from the shape of this strap. The overall width of the strap *a* is the same as that of the inner strap *b*. This form of joint is more expensive to make than an ordinary double-strap butt joint and is seldom used in boiler practice, except for the shells of Scotch boilers; but it enables better calking to be done along the edges of the outer cover-

plate. By calking, is meant the forcing of the edge of the plate or rivet into close contact with the plate, so as to produce a steam-tight joint. It should be observed that the rivets in a



(a) (b)

FIG. 10

double-strap butt joint are in double shear; that is, it is necessary to shear each one along two sections to tear the joint apart by shearing off the rivets.

ARRANGEMENTS OF RIVETED JOINTS

11. Location of Longitudinal Seams in Shell Boilers. Owing to the high furnace temperatures, the eroding action of the fuel gases, and the number of overlaps in the plates, it is customary to locate the longitudinal seams of shell boilers as far as possible from the fire. Shell boilers of the horizontal return-tubular type usually have two or more sections, or *courses,* with only one longitudinal seam to the course. The longitudinal seams are so arranged that they *break joints,* or alternate, as shown at a and a', Fig. 11; that is, the longitudinal seams in adjacent courses are not in one line, but one seam is to the right and the other to the left of the center. Each

seam is midway between the top and the side of the boiler. This arrangement of the seams permits the dome *b* to be installed, if one is required, and also the brackets *c*, without interfering with the joint construction.

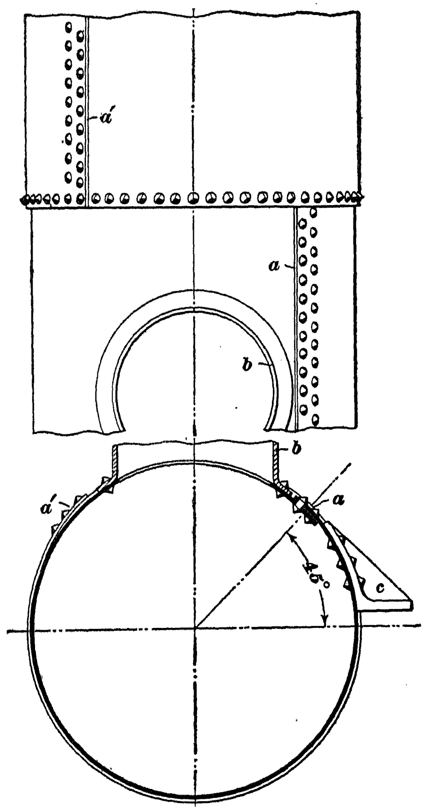


FIG. 11

12. Location of Longitudinal Joints in Internally Fired Furnaces.—In plain cylindrical furnace flues of internally fired boilers the longitudinal joint, as shown in Fig. 12, is generally located just below the grate, either to the right, as in the illustration, or to the left. The distance *s* is made as large as possible in order that the seam will not interfere with cleaning out the ashes.

In a vertical tubular boiler, the longitudinal (vertical) seam, if the boiler has only one course, may be located wherever convenient, provided it is clear of the fire-door opening. If the boiler has two or more courses, the longitudinal seams should break, or alternate.

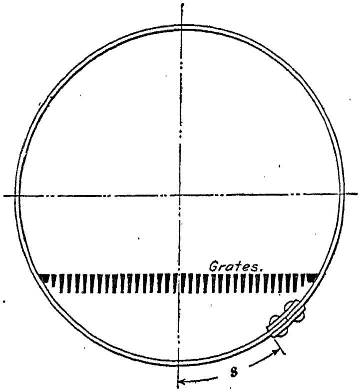


FIG. 12

13. Connecting Longitudinal Lap Joints at Girth Seam.—If plates lap together at the girth seams in boilers having longitudinal lap joints, the inner end *a*, Fig. 13, of the plate must be hammered out thin or scarfed, as it is commonly called, at the corner *b*. The outer end *c* of the plate is bent circular so as to fit the scarfed corner of *a*. If the lap joint is double zigzag-riveted, as shown, it is customary to make the pitch of all the rivets in the outer row uniform; in the inner row, the distance *d* from the rivet in the girth seam to the first rivet of the longitudinal seam will then be equal to $1\frac{1}{2}$ times the pitch.

14. Connecting Single-Strap Butt Joint and Girth Seam. In the case of butt joints having single cover-plates, the junction of the longitudinal seam and the girth seam is made as shown in Fig. 14. The larger shell course *a* overlaps the smaller course *b*, thus forming the girth seam *c*. The butt strap *d* extends to the outer overlapping edge of the larger course *a* and the rivets *e* of the girth seam pass through the shell plates *a* and *b* and the strap *d*. In staggered riveting,

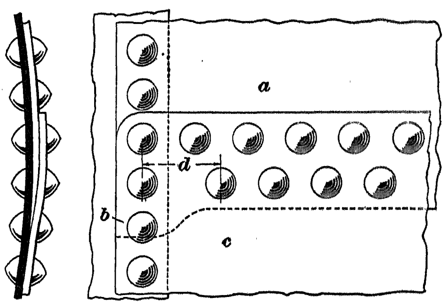


FIG. 13

the rivets in the butt joint adjoining the girth seam are usually pitched as explained in the preceding article.

15. In single-riveted longitudinal lap joints and butt joints it frequently is necessary, in order that the rivet die used on the inner head of the rivet may clear the inner edge *a*, Fig. 15, of the girth seam, to make the pitch *b* greater than the pitch of the rivets in the longitudinal seam. The inner end of the plate *c* is scarfed at the junction of the two courses, and the outer end of the plate *d* is bent to fit properly over the plate *c* and make a tight joint.

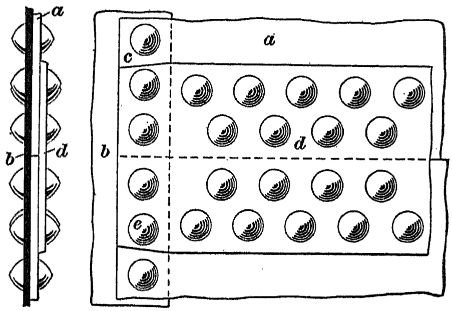


FIG. 14

16. Longitudinal Seam at Smokebox of Locomotive Boiler.—In boilers of the locomotive type, having double-strap butt joints, the joints at the smokebox end may be arranged as shown in Fig. 16. The end course *a* extends beyond the tube-sheet *b* so that the smokebox course *c* can be riveted to it. The tube-sheet *b* is flanged outwards so that it can be riveted to the shell courses *a* and *c*. From this arrangement of the tube-sheet, or head *b*, it is said to be *backed in*. The outer butt strap *d* at the smokebox end is flush with the outer edge of the flange of the head *b*, and the inner strap *c* is scarfed at the end to fit the curvature of the flange. The rivets in the girth seam at the smokebox end pass through the shell *a*, the flange of the head *b*, and the butt strap *d*.

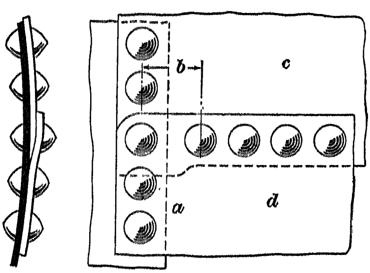


FIG. 15

The connection of the girth seam *f* and the longitudinal seam is made by extending the inner butt strap *e* to the edge of the course *a*. The external strap *d* is either made straight and butted against the plate *g* or else it is scarfed and placed under the larger course *g*. In the former case, sufficient space must

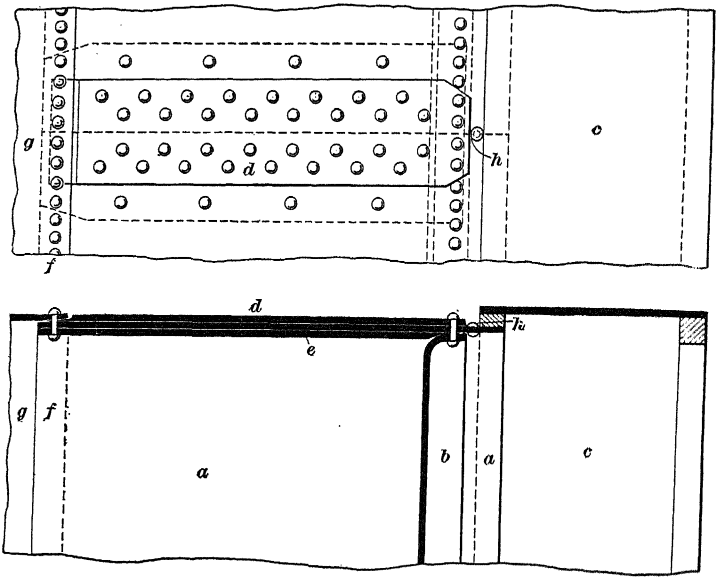


FIG. 16

be allowed between the shell and the butt strap for calking the seam. To prevent leakage at the junction of the butt joint and the smokebox, a *stop-rivet* *h* is used. It is usually a plug $\frac{3}{4}$ or $\frac{7}{8}$ inch in diameter, threaded and screwed tightly into the sheet *a*, after which both ends are formed into heads and then calked.

17. Connecting Double-Strap Butt Joint and Girth Seam. In a horizontal return-tubular boiler having three courses, as in Fig. 17 (*a*) and (*b*), the middle course *a* is slightly smaller in diameter and fits inside the two end courses *b* and *c*. The outer butt strap *d* of the longitudinal seam of the small course is scarfed at both ends and placed under the plate of the larger

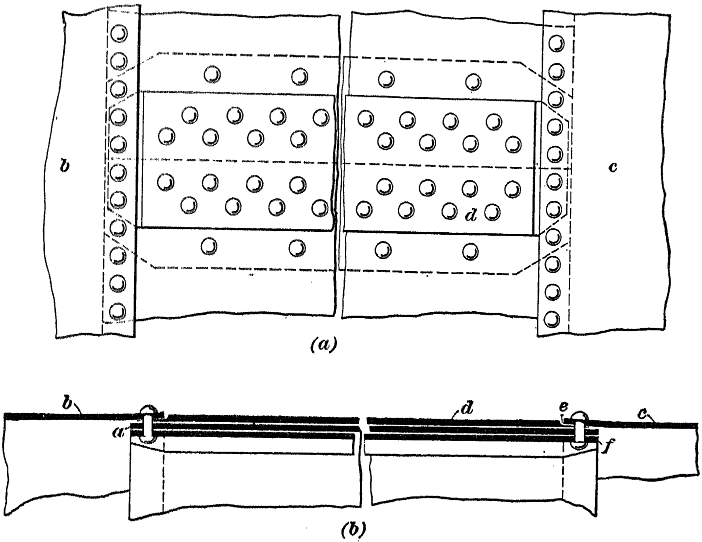


FIG. 17

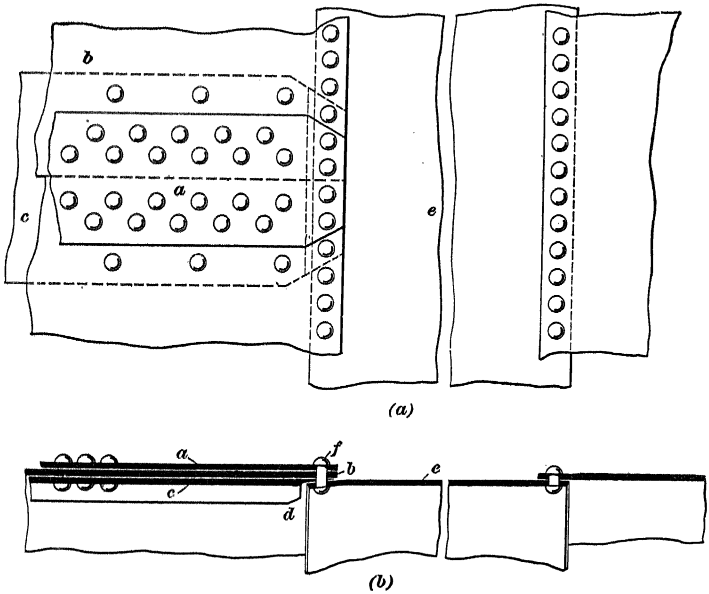


FIG. 18

courses *b* and *c* as shown at *e* in the sectional view (*b*). The inner butt strap *f* is not scarfed and extends the full length of the middle course *a*.

The arrangement of the girth seam and the longitudinal seams in the end courses is illustrated in Fig. 18 (*a*) and (*b*). The outer butt strap *a* is made equal to the length of the end course *b*. The inner butt-strap *c* is usually scarfed at both ends, as indicated at *d*. At one end it is passed over the flange of the tube-sheet and at the other end over the middle course *c*

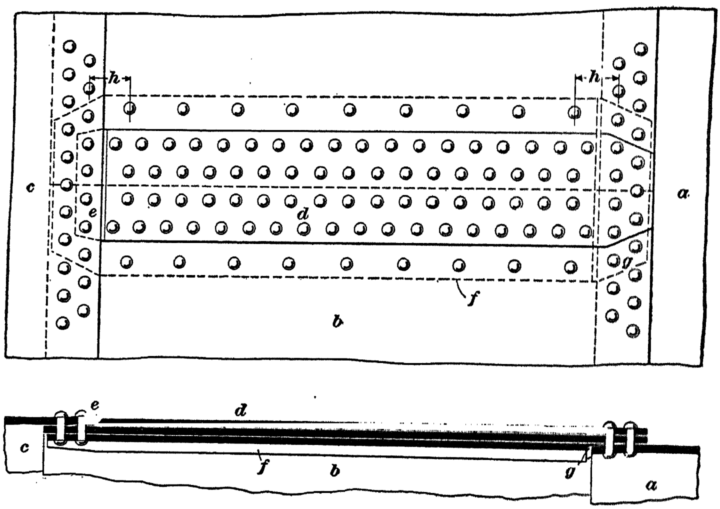
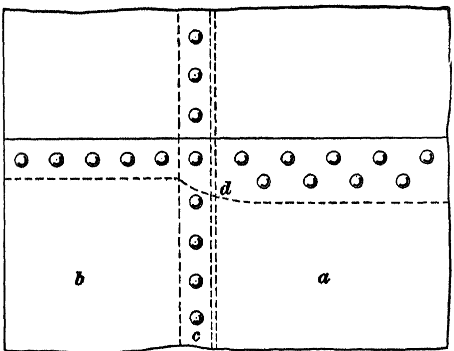


FIG. 19

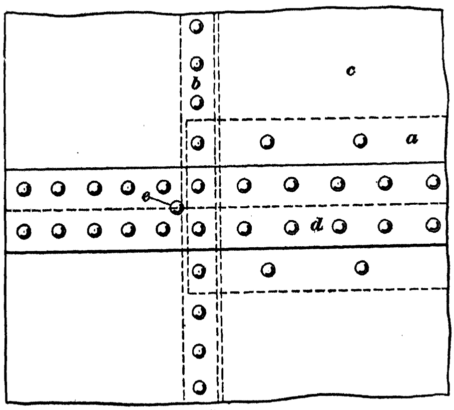
at the girth seam *f*. In the return-tubular boiler, the heads or tube-sheets usually have their flanges placed inside the boiler; but there are types having the shell forming the smokebox as shown in Fig. 16, and in such a case the head at the smokebox end is backed in.

18. Seam Connections of Shells of Locomotive Boilers. An approved arrangement of the circumferential and longitudinal seams of the first, second, and third courses of a locomotive boiler is shown in Fig. 19. The circumferential seams are double-riveted and the longitudinal seams have double butt

straps, with the inner strap wider than the outer one, alternate rivets being omitted in the outer row. It is the usual practice to make the first course *a*, to which the front tube-sheet is riveted, the smallest; the second course *b* fits outside of the course *a*, and the third course *c* fits outside of the course *b*. The outer butt strap *d* of the longitudinal joint of the second course *b* is of full thickness at the girth seam between the courses *a* and *b*, but is scarfed sufficiently at the seam between the courses *b* and *c* to go under the first row of rivets, as shown at *e*. The plate of the course *c* is bent upwards slightly to give room for the scarfed end of the strap *d*. The inner butt strap *f* is of full thickness at the girth seam between the courses *b* and *c* and extends far enough to take both rows of rivets. At the girth seam between the courses *a* and *b*, the butt strap is scarfed, as shown at *g*, and lies on top of the first course, the plate *a* being bent downwards slightly to accommodate the scarfed end of the strap *f*. The distance *h* from the girth-seam rivets to the first rivet in the outer row of the longitudinal seam should be the same at both ends.



(a)

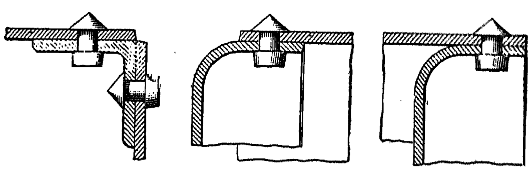


(b)

FIG. 20

19. Arrangement of Smokebox Joints.—In the locomotive type of boiler, which always has a smokebox, and in the horizontal return-tubular boiler, which may have one, the smokebox may be a separate course, or the first course may be extended, serving for both the smokebox and the first course. The first mentioned construction is customary for large boilers, and the second one for small boilers. In boilers having double-riveted longitudinal lap joints and the first course and smokebox made of one sheet, there is no need of double-riveting the longitudinal joint of the smokebox, as it is not subject to pressure. The usual method of arranging the seams is shown in Fig. 20 (*a*). In this illustration, part of the first course is shown at *a*; the smokebox end of the sheet, at *b*; and the front flue sheet, or round head, which is backed in, at *c*. Because the smokebox is single-riveted while the shell sheet is double-riveted, the shell sheet is cut away as shown. The inside of the shell plate is scarfed at *d* in order that a tight joint can be made between it and the head *c*.

20. In a boiler having the first course and the smokebox made of one sheet and a longitudinal double-riveted double-strap butt joint, it is the usual practice to scarf the inner butt strap *a*, Fig. 20 (*b*), and insert the scarfed end between the flanged head *b* and the shell sheet *c*. The outer butt strap *d* is made long enough to reach to the end of the smokebox and is single-riveted, as shown. A stop-rivet *e* is placed at the edge of the flange of the front head.



(*a*) (*b*) (*c*)

FIG. 21

21. Methods of Making Angular Connections.—There are various ways of making angular connections in structural and boiler work. Some of the methods are illustrated in Fig. 21. For structural work, such as tanks, breechings, and bases for

boilers, the plates can be readily joined by riveting them to an angle iron, as shown in (*a*). For boiler work, in which the ends of the shells are closed in, it is the usual practice to use flanged heads, as shown in (*b*) and (*c*). The head in (*b*) is turned with the flange inwards and in (*c*) it faces outwards.

Two ways of connecting an internal furnace to a tube-sheet are shown in Fig. 22 (*a*) and (*b*). To make the connection shown in (*a*), the tube-sheet *a* must have a flange *b* turned *inwards*. The furnace *c* is then brought flush with the outer surface of the tube-sheet and riveted to the flange. The connection shown in (*b*) is made by turning the flange *a* outwards and riveting it to the furnace *b*, which is set flush with the outer edge of the flange. This method requires a longer shell *b*, but it permits the riveting to be done on the outside.

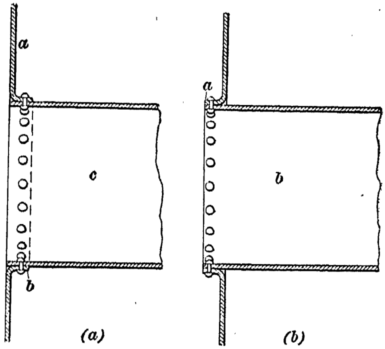


FIG. 22

ARRANGEMENT OF FIREBOX JOINTS

22. Fire-Door and Mud-Ring Connections.—A method of forming the fire-door hole for the furnace of a vertical boiler is shown in Fig. 23, the same method being also used to some extent with the smaller types of locomotive boilers used for stationary purposes. The door ring *a* is usually a steel casting or a wrought-iron ring placed between the shell plate and the furnace plate, and riveted with a single row of rivets. An objection to placing the door ring in this way is that it is so rigid that it prevents free expansion of the furnace plate, which causes leaks within a short time along the calking edge *b* and at the inner rivet heads *c*. The bottom of the water space may be closed by forming an ogee flange *d* on the furnace sheet and then riveting it to the shell. This construction, however, is not adopted when the furnace plate is rela-

tively thin or the water space at the bottom very large, because the thickness of the sheet will be reduced considerably by the operation of flanging.

23. In locomotive-type boilers, the fire-door hole is usually constructed as shown in Fig. 24. The door sheet *a* of the furnace is flanged outwards and the back head *b* is flanged inwards,

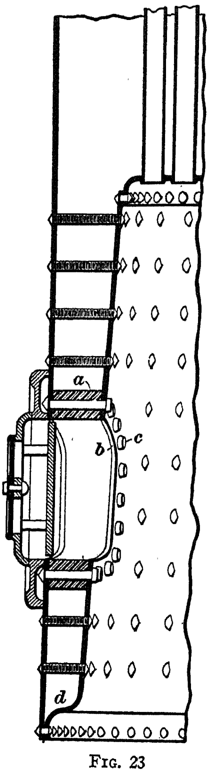


Fig. 23

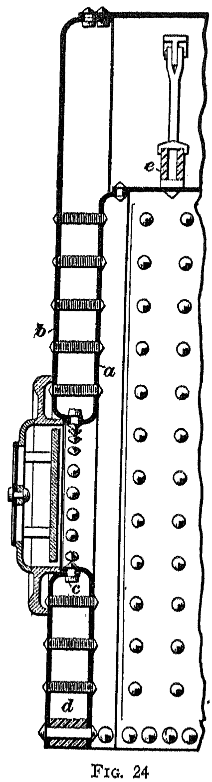


Fig. 24

the two flanges being united by a row of rivets *c*. The bottom of the water leg must not be closed by flanging the furnace sheets, as this would prevent the holding on and driving of the rivets *c*. It is closed by placing a mud-ring *d* between the furnace sheets and the outer plates and securing the ring to the sheets with rivets. The mud-ring is usually made of wrought iron, although cast-steel rings are extensively used.

24. Experience has shown that in fire-door holes constructed as shown in Fig. 24 the inner sheet will sooner or later crack from the calking edge to the rivet holes *c*, and also in the curved part of the flange. The inner, or furnace, sheet *a* is highly heated when the boiler is in use, but owing to the rigidity of the flange and the joint at the fire-door hole, aided by the adjoining staybolts, the flanged part of the fire-door of the furnace sheet cannot expand as freely as the other parts of the sheet, and stresses are thus set up in this part. Every time the fire-door is opened the stresses are intensified by the inrush of cold air that cools the joint and causes contraction. The repeated bending of the material under these stresses will ultimately cause rupture at one or more places. A collection of sediment on top of the fire-door hole leads to overheating and increases the danger of cracking the plates.

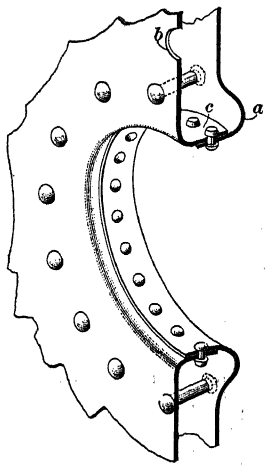


FIG. 25

25. To lessen the danger of cracking at the fire-door holes, the construction illustrated in Fig. 25 has been devised. The end sheet of the furnace is flanged to an ogee curve having radii as shown at *a*; for this reason, the furnace sheet is rendered rather flexible at the fire-door hole. A good-sized washout hole *b* placed directly over the fire-door permits the ready removal of foreign matter that collects around the top of the door flanges at *c*. In Fig. 26 (*a*) to (*c*) are shown several other forms of construction for door-hole openings.

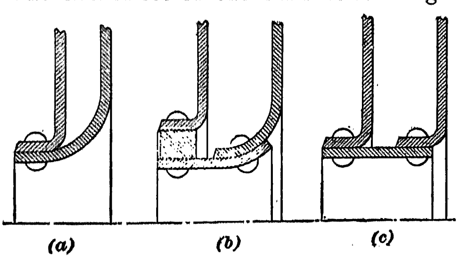


FIG. 26

26. Connecting Sheets to Mud-Rings.—In large locomotive-type boilers the bottom of the water leg is closed by a wrought-iron or steel mud-ring. In modern practice, the ring is made of sufficient depth to project about $\frac{1}{2}$ inch below the lower edge *a*, Fig. 27, of the furnace and water-leg sheets, thus permitting the edges to be calked from the sides. If the mud-ring does not project below the lower edges of the sheets, leaky calking edges are calked with great difficulty, especially if the boiler is standing on a frame or foundation. To prevent the mud-ring from cracking at the corners, it is good practice to provide a boss *b* at each corner. The extra metal in the boss will counteract the weakening effect of the holes drilled for the *corner bolts,* which are bolts used to fasten the sheets to

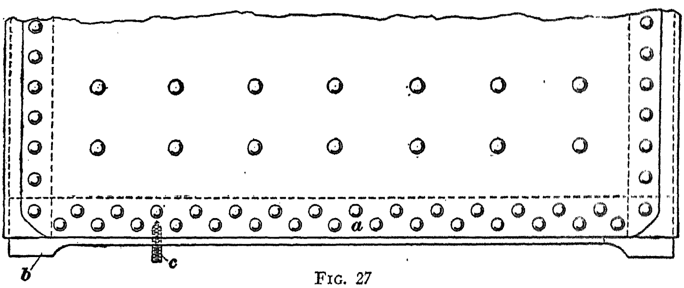


FIG. 27

the mud-ring at the corners. Mud-rings for boilers carrying medium pressures are generally single-riveted; for high-pressure boilers, double zigzag riveting is considered good practice.

27. When studs are to be screwed into mud-rings for attaching an ash-pan or for a similar purpose, the studs must be so located as to clear the rivets. In a single-riveted mud-ring, the studs should be placed midway between rivets; in a double-riveted mud-ring, they should be placed directly beneath a rivet of the upper row, as shown at *c*, Fig. 27.

28. In modern practice, mud-rings are machined both inside and outside, thus eliminating the expensive and difficult work required to make the sheets fit metal to metal over an unfinished or rough mud-ring. The corners of mud-rings should be shaped as illustrated in the plan view, Fig. 28 (*a*). This con-

struction makes the flange of the furnace sheet *a* and the outside firebox sheet *b* lie flat. The furnace side sheet *c* and the boiler head *d* are scarfed to go under the sheets *a* and *b*. If the corners of the mud-ring are shaped as shown in (*b*), the

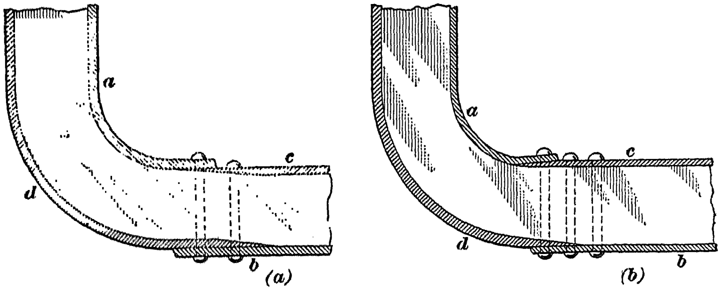


FIG. 28

flanged furnace sheet *a* will have to be bent inwards to go over the scarfing of the furnace side sheet *c*, and the outer firebox sheet *b* will have to be bent outwards to go over the scarfing of the boiler head *d*. Such construction is not only expensive and unsightly, but it also requires three lengths of rivets at the joints, whereas only two lengths of rivets will be required if the corner is laid out as shown in (*a*).

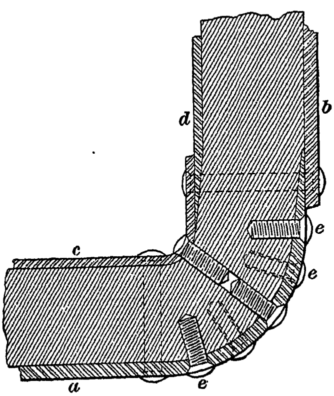


FIG. 29

29. The outside sheets of firebox boilers are fastened to the corners of the mud-rings by threaded corner bolts, the number and arrangement at each corner depending on the radius of the corner and whether the sheets are single-riveted or double-riveted to the mud-ring. A usual arrangement of corner bolts is shown in Fig. 29, in which the boiler head is shown at *a*, the outer firebox sheet at *b*, the flanged furnace sheet at *c*, and the furnace side sheet at *d*. The sheets *a* and *c* are first laid against the mud-ring, after which the holes

for the corner bolts e are drilled through the sheets a and c into the mud-ring. The holes are then tapped, and enlarged or countersunk in the plates a and c, so that the heads of the corner bolts will be similar to oval countersunk rivet heads. Instead of using corner bolts with oval heads, some mechanics thread a rod and screw it into the mud-ring. This rod is then cut off, sufficient material being left to form a head, and the projecting ends are riveted over, thus filling the countersunk holes in the plates a and c. The edges of the bolt heads are always calked down to the sheet. In the illustration, corner bolts are used at the corner, but very often rivets are used at this point.

30. In Fig. 30 (a) is illustrated a longitudinal section and in (b) a cross-section of a firebox corner, showing the con-

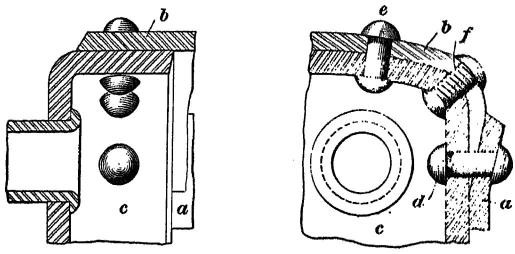


FIG. 30

nection between the side sheet a, the crown sheet b, and the tube-sheet c. If the tube-sheet is flanged to a very small radius in the corner, it is very difficult to drive a rivet properly midway between the rivets d and e in (b), that is, directly in the corner. The usual practice is to drill and tap a hole at this point, generally using a tap $\frac{3}{4}$ inch in diameter and having twelve threads per inch. A plug f is then screwed tightly into the tapped hole and its ends are riveted over and calked.

31. Fire-Cracks in Joints.—It has been found by experience that in firebox boilers the furnace side of the furnace sheets is liable to crack at the joints from the rivet holes outwards toward the edge of the plate, such cracks being termed *fire-cracks*. The lap joints are kept relatively cool on the

water side, but the fire side of the lap, especially with thick plates, becomes so hot as to set up stresses that ultimately result in cracks. To reduce the liability that fire-cracks will occur, it is the practice to bevel the furnace side of the lap from *a*, Fig. 31, to the edge *b*, countersink the rivet holes, and drive oval countersunk rivets *c*. The thinning of the material assists the water on the water side in keeping the furnace side of the lap cool, and does not reduce the strength of the joint, as the pressure tending to rupture the joint acts in the direction of the arrow.

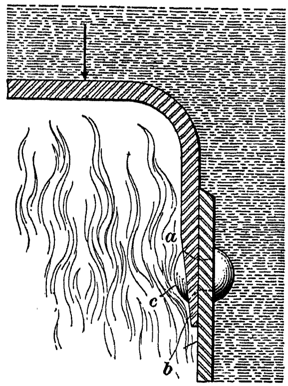


FIG. 31

32. In an externally fired boiler of the horizontal return-tubular or flue type, part of the girth seam is exposed to the flames and fire-cracks may occur on the fire side of the seam. As the internal pressure, indicated by the arrows in Fig. 32 (*a*) and (*b*) tends to pull the lap apart and to crush or shear out the metal between the rivet holes and the edge of the plate, the lap should not be beveled as shown in Fig. 31, because this would materially weaken the joint. A common construction at the girth seams is shown in Fig. 32 (*a*), the rivet having an oval head on the fire side. If, however, the rivet is made with a countersunk head on the fire side, as shown in (*b*), there

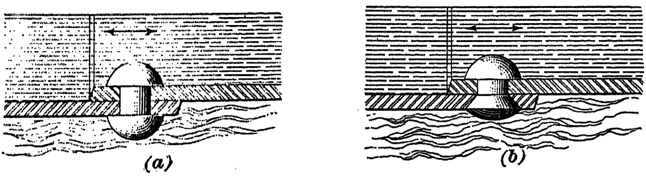


FIG. 32

will be less material at the joint without greatly weakening the plate; consequently, the water will tend to maintain a more nearly uniform temperature at the lap, thereby reducing the liability of the occurrence of fire-cracks.

HEADS OF BOILERS AND DRUMS

FLAT HEADS

33. The tube-sheets of locomotive, vertical, flue, and horizontal return-tubular boilers are flat circular plates with flanges at the outer edges, by which they are riveted to the shells of the boilers. As a general rule, the tube-sheet, or head, is inserted in the manner shown in Fig. 21 (*b*); that is, the edge of the flange is inside the shell and the convex part

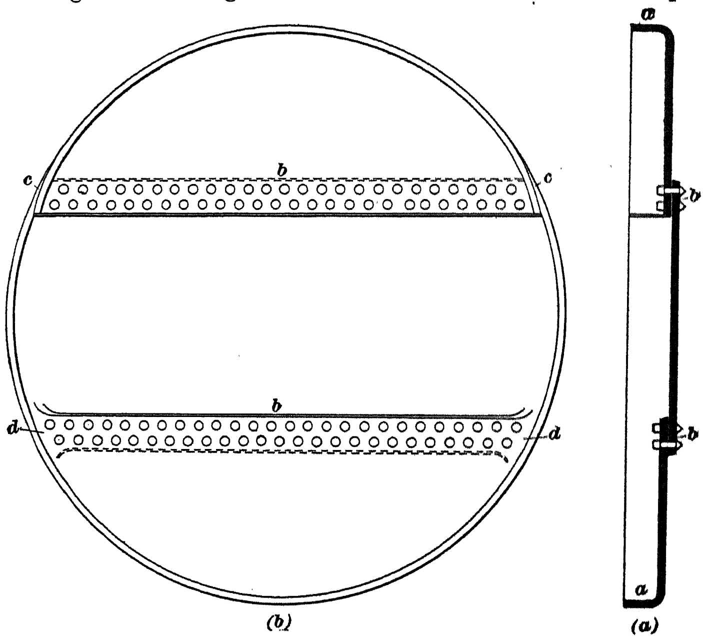


FIG. 33

of the flange faces outwards. However, it is not uncommon for the head to be backed in, as in (*c*), in which case the flat part of the head lies well within the outer end of the shell. As flat surfaces are not self-supporting when subjected to pressure, the flat heads of boilers are braced by diagonal stays above the tubes and by through stays, from head to head, below the tubes and on each side of the manhole

34. It is customary to make the head of a boiler of a single piece of plate; but if the boiler is of great diameter, the head must be built up of two or three sections riveted together. For example, Fig. 33 (*a*) and (*b*) shows the back head of a marine boiler of the Scotch type, which is of such diameter that it is made of three plates that are flanged separately, as at *a*, and then riveted together. After the flanging has been done, the sections are fitted together and the positions of the rivet holes *b* are marked. A few rivet holes are drilled and

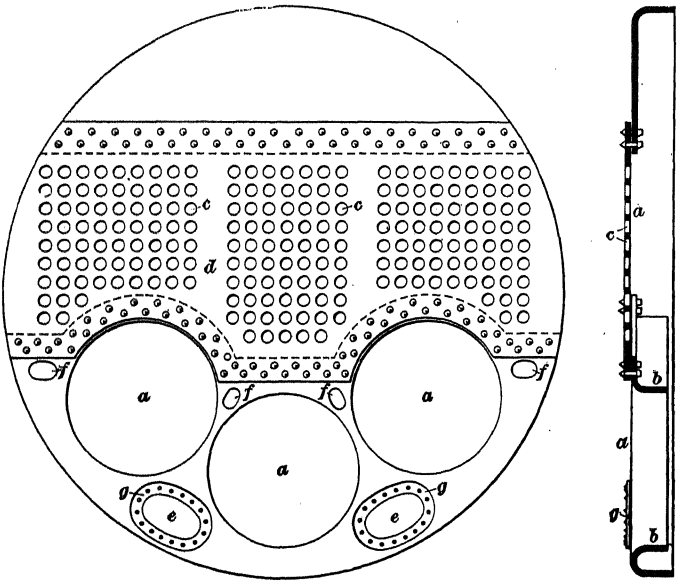


Fig. 34

bolts are inserted to hold the sections together in their correct relative positions, after which the remaining holes are drilled. If the flanges of adjoining sections are lapped, as at *c*, the outer flange is scarfed and the inner one set in a trifle, as shown. In some cases, however, the flanges are welded together, as at *d*.

The front head of a Scotch boiler having three openings *a* for the furnace connection is shown in Fig. 34. The openings are cut in the lower sheet and the flange required for riveting

the furnaces to the head is turned in as shown at *b* in the sectional view. The tube holes *c* are drilled in the section *d* and the manholes *e* and handhole openings *f* are cut in the lower plate. The manhole openings may be flanged in, in the same manner as the furnace openings, or they may be reinforced by riveting wrought-iron or steel rings to the head, as shown at *g*.

BUMPED HEADS

35. Heads that are bent to the convex and concave forms shown in the sectional views, Fig. 35 (*a*) and (*b*), are called *bumped heads*, or *dished heads*. They are used in plain cylindrical boilers, steam drums, mud-drums, oil tanks, air reservoirs, etc. The head in (*a*) is convex outwards and is therefore a convex head, whereas the head in (*b*) is concave outwards and is a concave head. A dished head backed in, as shown in (*b*), is used only in cases where there is in the shell no opening large enough to permit the driving of the rivets.

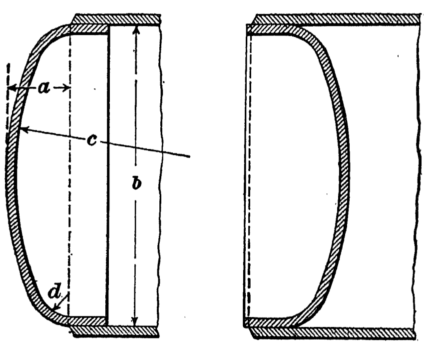
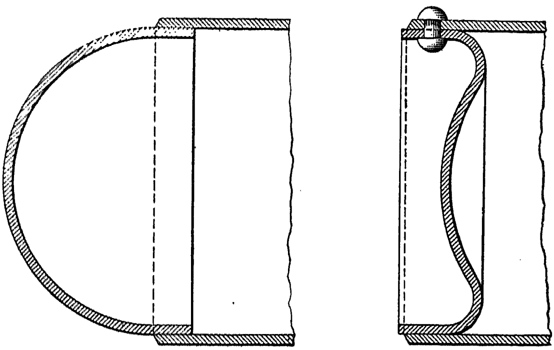


FIG. 35

Dished heads with the pressure on the convex side of the head, as in (*b*), are not so strong to resist pressure as heads having the pressure on the concave side, as in (*a*). The A. S. M. E. Boiler Code provides that a bumped head having the pressure against the convex face, as in (*b*), shall be allowed a maximum working pressure of only 60 per cent. of that for a bumped head of the same dimensions but having the pressure against the concave face, as in (*a*).

The depth *a* of the dished part of the head depends on the inside diameter *b* of the shell to which the head is riveted. The curve of the dished head has a radius *c* equal to the inside diameter *b* of the shell. The corner radius *d* is not less than

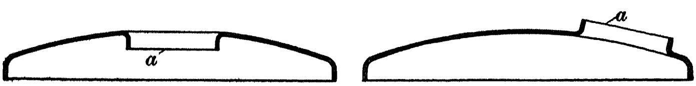
$1\frac{1}{2}$ inches nor more than 4 inches. A bumped head arranged as in (*a*) is self-supporting for certain working pressures, since the head is a section or segment of a sphere and is already curved to the shape it would naturally assume under pressure.



(*a*) (*b*)

FIG. 36

36. The strongest form of dished head is the *hemispherical head,* Fig. 36 (*a*), which is used in some types of cylindrical boilers built in England. The form of head illustrated in Fig. 36 (*b*) is used in tank work; the objections to it are that



(*a*) FIG. 37 (*b*)

there is difficulty in shaping it and in maintaining tight rivets at its joint with the shell. Bumped heads may have manhole openings flanged inwards or outwards, as shown in Fig. 37 (*a*) and (*b*), respectively. These flanged openings are known as plain flanged manholes. In the flanging process, the metal is stretched along the face *a* of the flange, and this condition is more pronounced in light-plate than in heavy-plate flanging. To compensate for the reduction in plate thickness and to give greater stiffness and strength to the flange *a,* a steel band or ring *b* may be shrunk on the flange and secured to it by studs *c,* as shown in Fig. 38.

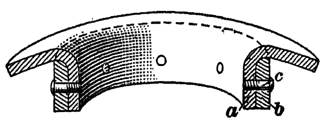


FIG. 38

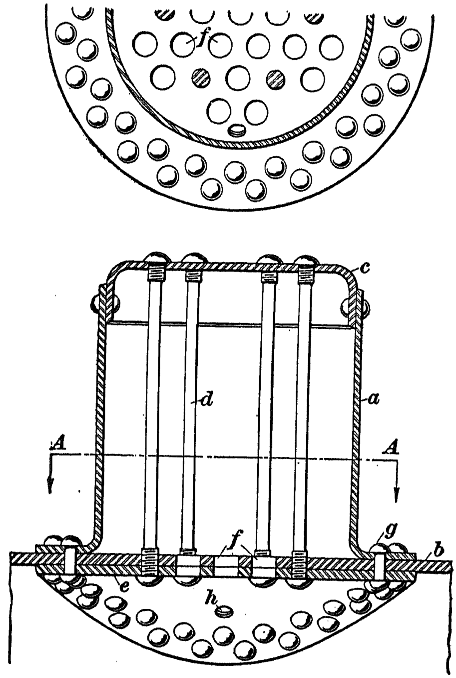
DOMES AND DRUMS

STEAM DOMES

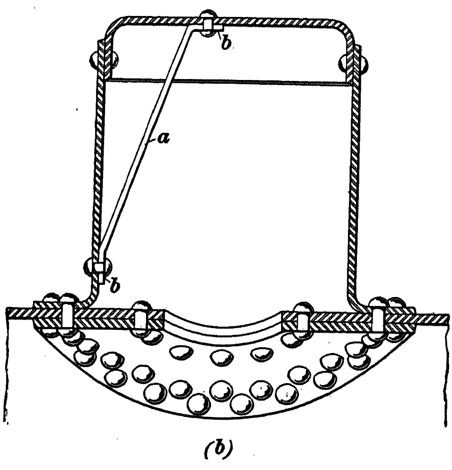
37. Domes on Stationary Boilers.—In small fire-tube boilers of the locomotive, horizontal return-tubular, and flue types, domes of the form shown in Fig. 39 are very often attached at the top of the boiler shell. A dome is placed on a boiler for the purpose of increasing the steam space and also for the purpose of obtaining drier steam, the supposition being that the steam will be drier on account of its being farther removed from the water. The dome shell *a* in (*a*) is flanged and riveted to the boiler shell *b*. A flanged head *c* closes the dome at the top. To support the flat surface of the head, either of the methods of bracing shown in (*a*) and (*b*) may be employed. In (*a*) the stays *d* are threaded and screwed into the boiler plate *b*, the dome liner *e*, and the head *c*, and the ends are then headed over. The method of bracing shown in (*b*) consists of using diagonal braces *a* having at each end a palm or foot *b* parallel to the surface to which it is riveted.

38. Communication between the steam space and the dome may be provided by cutting a number of small holes *f*, Fig. 39 (*a*), through the shell plate below the dome; or, a single opening may be cut in the boiler shell, as in (*b*). In either case the total cross-sectional area of the opening or openings should be greater than the area of the steam outlet. The openings in the shell reduce its strength, and to compensate for its weakened condition the practice is to rivet a reinforcing ring, or liner, around the dome connection as at *e* in (*a*). The rivets *g* that hold the dome to the shell pass through both the liner and the shell. Drain holes *h* are also provided in the boiler shell near the lowest point of the junction of the base of the dome and the boiler shell. Water that collects from the condensation of steam flows back through these holes into the boiler.

An approximate rule for determining the size and height of a steam dome is to make its diameter equal to one-half the



(a)



(b)

Fig. 39

diameter of the boiler, and its height equal to nine-sixteenths of the diameter of the boiler.

39. Locomotive Boiler Domes.—The domes of locomotive boilers are usually made of heavier plate than those of stationary boilers. The principal types of locomotive domes are shown in Figs. 40 and 41. The three-piece dome shown in Fig. 40, which is quite common, is made with a heavy collar or base *a*, from $\frac{3}{4}$ to 1 inch in thickness, having two flanges of about the same length. One of these flanges is riveted to the boiler shell and the other to the dome shell *b*. The shell *b* is made of lighter plate than the dome base and is closed at the top by a flanged flat head *c*. Domes are also formed in one piece, as illustrated in Fig. 41. This method of construction produces the strongest type of dome and offsets the need of several riveted joints. Such domes are pressed out of heavy plate, from $\frac{3}{4}$ to 1 inch thick. It will be noticed in (*a*) that the dome has a slight taper, being 29 inches in diameter at the top and 30 inches at the base. Owing to the heavy plate thickness the right-angle flanges are made with a large radius *a* of $4\frac{1}{2}$ inches, and a radius *b* of 3 inches is used for the larger flange angle, as shown in (*b*).

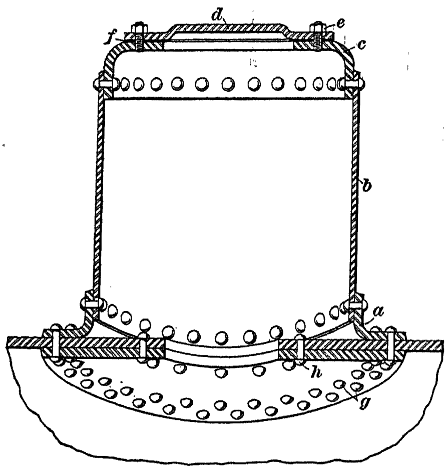
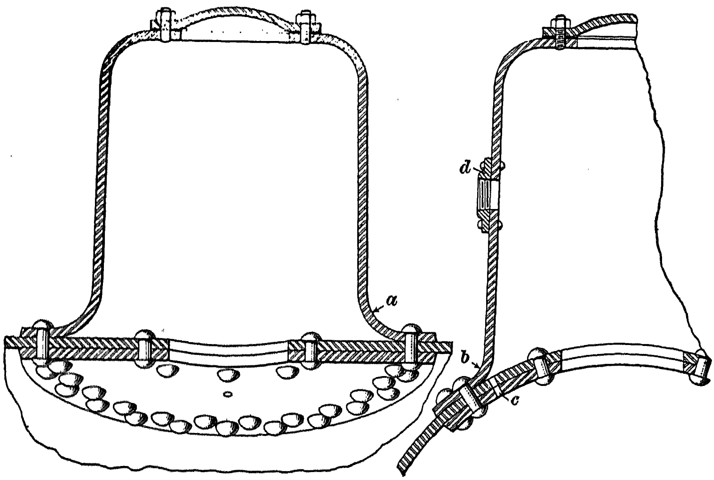


FIG. 40

40. In boilers of the locomotive type it is usually necessary to have a large opening in the dome head to permit the erection of the steam pipe and the throttle valve. Such an opening is circular in form and covered with a pressed-steel cap *d*, Fig. 40, which is fastened to the dome head by studs and nuts *e*. The upper surface of the dome head and the

bottom face of the cap *d* are faced or machined so that when the cap is bolted down on the copper gasket *f* a steam-tight joint will be obtained. The dome cap may be made in several ways. Sometimes it is straight, as shown, and sometimes it is dished, as indicated in Fig. 41. The latter form adds strength to the cap. To reinforce the opening in the shell, a steel reinforcing ring is riveted to the shell and the dome, as in



(a) (b)

FIG. 41

Fig. 40, with a double outer row of rivets *g* and a single inner row of rivets *h*. Drip holes, as at *c*, Fig. 41 (*b*), are provided to drain away water that collects at the base of the dome. To attach the safety valve and the whistle to the dome, threaded flanges like the one shown at *d* are riveted to the side of the dome shell.

41. The Boiler Code of the A. S. M. E. requires that the longitudinal joint of a dome 24 inches or more in diameter shall be of butt and double-strap construction irrespective of pressure. When the maximum allowable pressure exceeds 100 pounds per square inch, the flange of a dome 24 inches or over in diameter shall be double-riveted to the shell. For domes less than 24 inches in diameter the longitudinal seam may be

of the lap-joint type, and the flange may be single-riveted to the boiler, provided that a factor of safety of not less than 8 is used in determining the allowable working pressure on the dome.

The corner radius of the flange, measured on the inside of the plate, shall equal at least twice the thickness of the plate, for plates 1 inch thick or less, and at least three times the plate thickness for plates over 1 inch in thickness.

The dome may be located on the barrel or over the firebox on traction, portable, and stationary boilers of the locomotive type, up to and including a shell diameter of 48 inches. For larger boiler diameters, the dome shall be located on the shell of the boiler.

42. Dry Pipe.—The use of steam domes is giving way to the practice of installing larger boilers with the required steam space and placing inside a fitting known as a *dry pipe*. It is usually made as shown in Fig. 42. The central section *a* is a tee into which are screwed the pipes *l* and *c* and the nipple *d*. The pipes *b* and *c* are slotted along the top, or else holes are drilled through them, as shown. The combined area of these openings should be larger than the cross-sectional area of the steam outlet *e*. It is usually one-third greater than the area of the steam outlet. The ends of the dry pipe are closed with caps *f* and at the bottom of the pipe a drip hole is drilled to allow water to drain out. The dry pipe should be connected at the highest point in the steam space of the boiler, and in such a manner that the steam can enter it through the perforations at the top. It is supported at the ends by iron straps *g* riveted to the drum *h*.

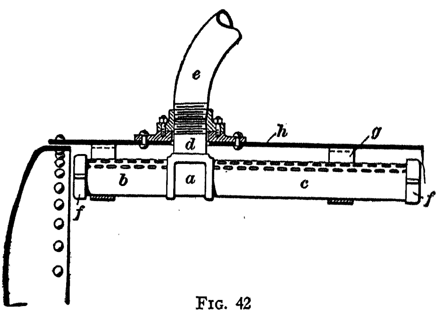
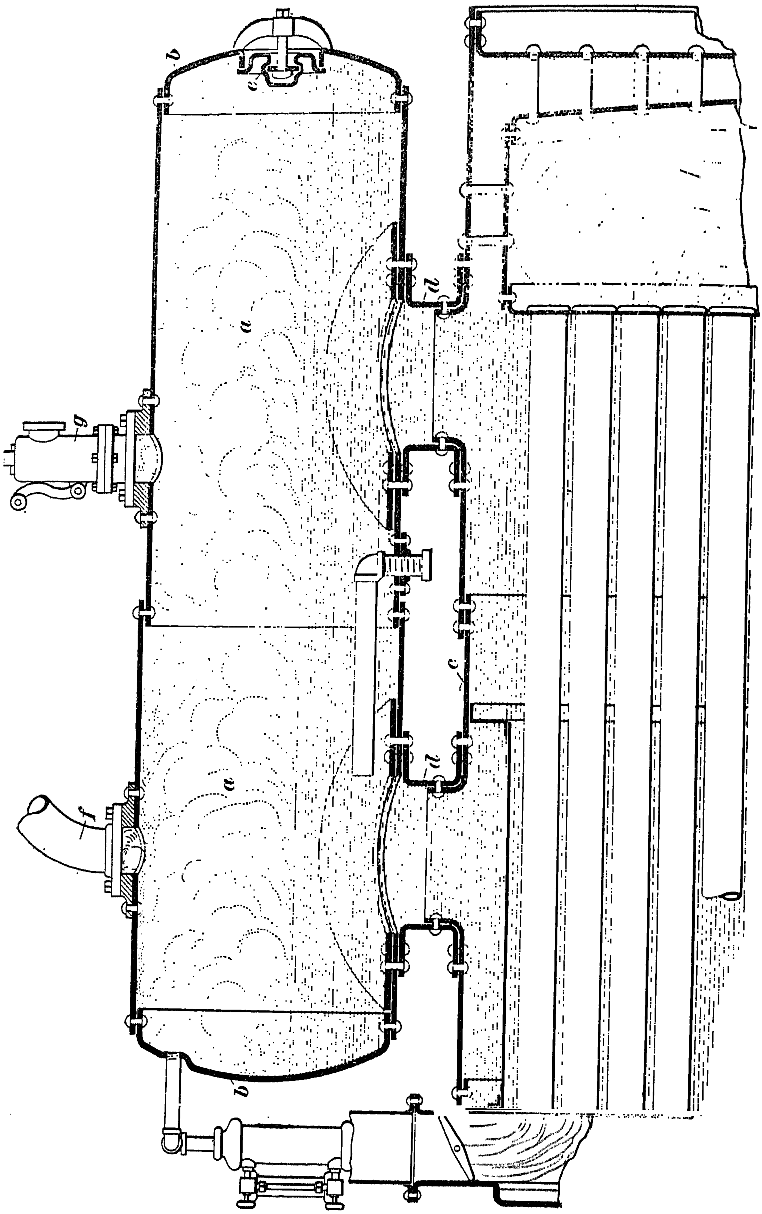


FIG. 42

STEAM DRUM

43. Purpose and Arrangement of Steam Drums.—The steam drum is a cylindrical vessel often attached at the top of a fire-tube boiler to increase the steam space, thus serving as a substitute for the steam dome. One form of steam drum attached to a fire-tube boiler is shown in Fig. 43. The drum is composed of two shell courses *a*, closed by two dished heads *b*, and is attached to the top of the shell *c* by two flanged steel nozzles *d*. There is some objection to this construction on account of unequal expansion and contraction stresses that arise in the boiler shell and drum, which may cause the nozzle seams to leak. To overcome this condition, one nozzle is sometimes used. To provide an entrance to the steam drum for cleaning, inspection, and repairs, a manhole *e* is placed in one of the dished heads. The steam outlet is connected at the top of the drum, as shown at *f*, and the safety valve is attached at *g*. The feedwater enters through the pipe at the bottom of the drum, passes down through the front nozzle and deposits much of its sludge in the pan beneath the nozzle.

44. A steam drum is not generally used on a single boiler, but it is often used if a number of boilers are set in a battery, the steam drum being connected directly to the top of each boiler. It is then placed transversely, and is usually connected to the boilers by long curved pipes, to allow for the expansion and contraction of the header. In most designs of water-tube boilers steam drums are used; however, they are partly filled with water. If each boiler in a battery has an independent furnace, there should be a stop-valve between each boiler and the steam drum, to allow each boiler to be cut out of service; if the battery of boilers has one furnace common to all, no stop-valve should ever be placed in the nozzle or pipe between each boiler and the drum. A single steam drum, when it is applied to a battery of boilers, is often called a *header*. If a header is applied to a battery of boilers that has a furnace common to all the boilers, one safety valve is sufficient for the entire battery; but if a header is connected with a battery of boilers, each of which has its own furnace and


v
e
g
a
d
c
d
a
f
b

stop-valve, an independent safety valve, attached directly to the shell, should be placed on each boiler of the battery.

45. Size and Strength of Steam Drums.—When a steam drum is used for a single boiler, its diameter may be made equal to one-half the diameter of the boiler, and its length equal to the diameter of the boiler. When one steam drum is common to several boilers, its diameter is usually made equal to half the diameter of one of the boilers, and its length equal to the horizontal outside-to-outside measurement over the several boiler shells.

The strength of steam drums may be determined by the rules governing the strength of boiler shells. They require just as rigid inspection as the boiler itself.

MUD-DRUMS AND BLOW-OFFS

46. Mud-Drums.—Cylindrical mud-drums made of steel in the same manner as the steam drum in Fig. 43 are sometimes used with stationary boilers of the fire-tube type. In such cases the drum is attached to the bottom of the boiler to provide a suitable place for the collection of mud and sediment held in suspension in the feedwater. The feedwater is sometimes introduced into the drum, from which it passes into the boiler. In shell boilers the mud-drum is located at the end farthest from the furnace, as shown in Fig. 44. The drum *a* rests on a standard *b* and is connected to the boiler shell by flanged nozzles *c*. A

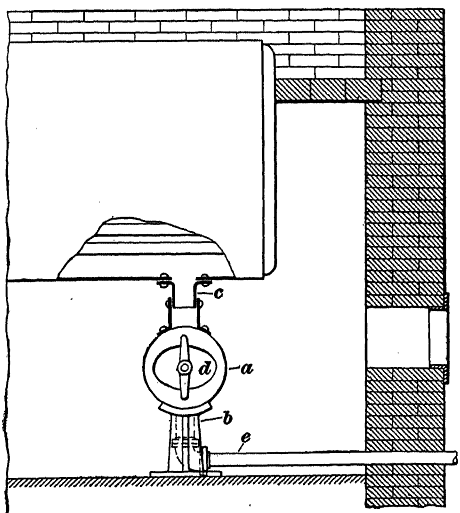


FIG. 44

manhole *d* is provided in the end of the drum for cleaning and repairs, and blow-off piping *e* is connected at the bottom of the drum for blowing out the mud and other sediment. A protecting wall of brick may be built in front of the drum when it is placed inside the boiler setting, so that it may not be directly exposed to the fire temperature. The difficulty arising in the use of such drums is that the mud deposited tends to become baked and hard, and unless the drum is frequently cleaned, there is danger of its becoming entirely clogged. In some types of water-tube boilers one or more cylindrical drums form water-drums and mud-drums, serving primarily to distribute the feedwater to the tubes and incidentally to collect mud and other feedwater sediment.

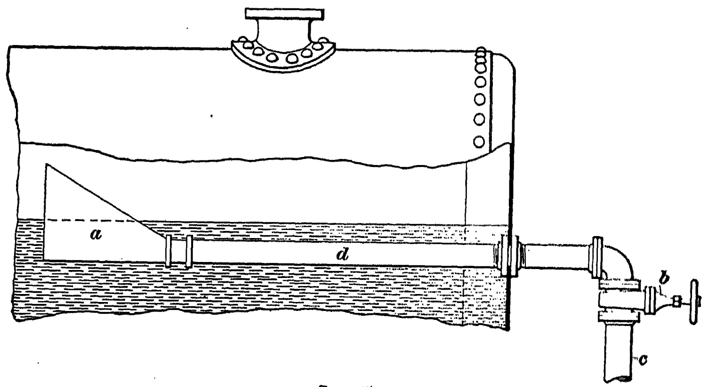


FIG. 45

47. Surface Blow-Off.—The surface blow-off *a*, Fig. 45, is a sheet-metal funnel or scoop so arranged that its outlet is submerged at the lowest water level and its upper edge at the highest water level. It should be placed at about one-third of the length of the boiler from the rear head. It is installed for the purpose of removing the scum and other impurities that rise to the surface of the water. When the valve *b* is opened, the steam pressure forces the scum and some water to flow out through the blow-off piping *c* which is usually connected to a blow-off tank. If the scum is not removed, it will prove detrimental to the operation of the boiler, for it will

prevent the steam bubbles from escaping freely, and some of the scum may be carried off with the steam into the power-plant auxiliaries, affecting their operation. Sometimes, the funnel *a* is fitted with floats and the pipe *d* is swiveled, so that the funnel will follow the rise and fall of the water level in the boiler.

48. Blow-Off Tank.—A blow-off tank is a cylindrical vessel made of boiler plate, as shown in Fig. 46, the shell *a* being riveted to dished heads *b*. The top head contains a manhole *c* to provide entrance into the tank for cleaning. A vent pipe *d* is provided at the top so as to prevent the accumulation of excessive pressure in the vessel. The blow-off pipe leading from the boiler is connected at *e* and the water is drained out through the pipes *f* and *g*. The purpose of the blow-off tank is to entrap the hot water blown off from the boiler, so that it will cool before being discharged into the sewer. By this arrangement the danger of damaging the sewer by hot water is avoided. The blow-off tank is provided with a siphon breaker *h* to prevent a siphoning action through the pipe *g*, as it is desired to keep the tank filled with water to the level of the overflow pipe *i*.

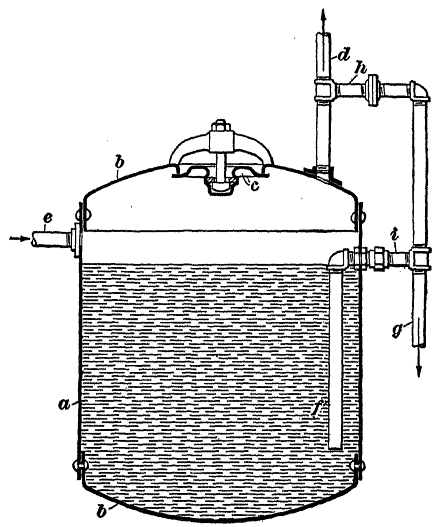


FIG. 46

OPENINGS IN BOILERS

STEAM, WATER, AND WASHOUT OPENINGS

49. Classes of Openings.—In all types of boilers, a number of holes, or openings, must be cut through the boiler shells, heads, domes, or drums for the outlet of steam, for the inlet and outlet of water, and for the purposes of cleaning, inspecting, and repairing. It is customary to designate each opening in accordance with the purpose it serves; thus, the hole through which the feedwater is admitted is the feedwater hole; the hole into which a gauge cock is screwed is the gauge-cock hole. An opening cut into a boiler for the purpose of washing out foreign matter and incidentally permitting inspection is an inspection hole, a washout hole, or a handhole, the last term being preferably used when the hole is large enough to admit the hand. When a hole is large enough to permit the passage of a man's body it is a manhole. One or more manholes should be placed in each boiler that is large enough to permit this, one manhole being placed in the front head and another in the boiler shell. Sometimes a manhole is placed in the rear head instead of in the boiler shell.

50. Washout Holes and Plugs.—In locomotive-type boilers, washout holes are placed in convenient places in the water legs below and above the tubes, for washing out mud and other sediment that collects in the boiler. These openings are threaded and plugged. Round brass plugs for closing washout holes are called *washout plugs*. They generally have twelve threads per inch, cut on a taper of $\frac{3}{4}$ inch per foot. Two types of washout plugs are used, differing only in the manner of receiving the wrench for screwing them in or out. The form shown in Fig. 47 (*a*) is a male plug, and is the one most generally used; the form shown in (*b*) is a female plug, and is used only where the projecting square shank of the male plug is not permissible. The body of the female plug is recessed to receive the wrench by which it is screwed into place.

51. Washout plugs are generally screwed directly into the sheet, as shown in Fig. 47 (*a*), but when placed in a part of the sheet curved to a very small radius, the sheet is flanged out and the plug is screwed into the flange, as shown in (*b*). The flanging of the sheet for a washout plug is necessary in such a case in order to provide a sufficient number of perfect threads for holding the plug and making

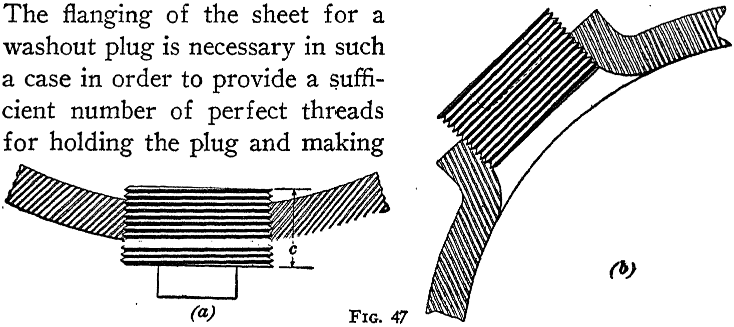


FIG. 47

it tight. The length *c* of the threaded part of the plug, as shown in (*a*), should be sufficient to give, when the plug has been screwed home, at least two threads inside and three or four threads outside the sheet into which it is screwed.

52. Handhole Openings and Cover-Plates.—Handhole openings may be made circular in form, but they are generally elliptical. The common sizes are 3 in. by 5 in., 4 in. by 6 in., 5 in. by 7 in., 6 in. by 8 in., and 6 in. by 10 in. They are made to fit either flat or bent plates. For stationary boilers two general types of handholes are used, one of which is shown in Fig. 48. It consists of a cast-iron or steel cover-plate *a* and a *yoke,* or *crab,* *b* of steel or cast iron. The bolt *c* passes through the cover-plate, which has a countersunk head riveted over at the end *d*. To produce a steam-tight joint, a gasket *e* is

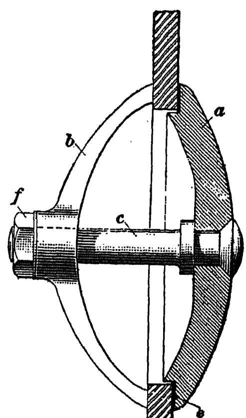


FIG. 48

placed between the boiler plate and the cover-plate; then, by tightening the nut *f*, the cover-plate is brought to bear against the gasket and plate. The gasket should be made of heat-

resisting and waterproof material when used for steam connections. Various compositions of rubber and asbestos are employed for this purpose. Before being placed in position the gasket should be coated on both sides with graphite in

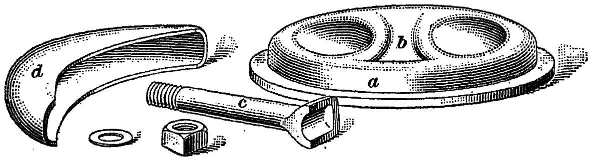


FIG. 49

order to prevent it from sticking to the metal when the cover is removed. It may then be used a number of times. The different parts of an elliptical pressed-steel handhole cover-plate are shown in Fig. 49. The plate *a* is formed under hydraulic pressure and the two curved transverse ribs provide

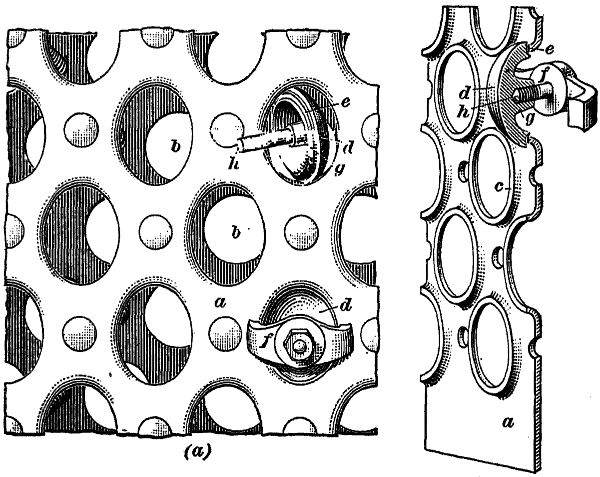


FIG. 50 (b)

a socket *b* into which is slipped the head of the bolt *c*. The yoke *d* is also of pressed steel, and the combination of plate and yoke gives a stronger and lighter form of handhole cover arrangement than the cast-iron or steel type.

53. Handholes for water-tube boilers are made either circular or elliptical. When the circular form is used, it is necessary to have a number of large elliptical handholes through which the covers for the adjoining circular handholes can be installed and removed. In Fig. 50 is illustrated the type of handhole equipment used in the Edge Moor water-tube boiler. The outer plate *a* opposite the point where each tube *b* enters the inner tube-sheet is pressed to form a raised elliptical seat *c*, as shown in the rear view of the plate *a*, given in (*b*). The edges of these seats are machined to provide smooth faces against which the handhole plates *d* can be drawn to produce steam-tight joints. A gasket *e* is placed between the plate and the handhole cover. The yoke *f* and the plate *d* are drop forgings and the plate is formed with a boss *g* that is threaded to receive the stud *h*.

54. In some makes of water-tube boilers, a special form of metal-to-metal handhole construction is used. It is known as the *Key handhole,* and is shown in Fig. 51. The handhole cover *a* is a plug or cap with tapering sides that match the taper of the opening cut in the boiler plate *b*. The plug is inserted from the inside, opposite the end of the tube *c*, and

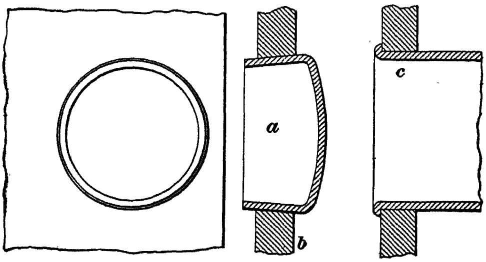


FIG. 51

is pulled into place from the outside by a special tool made for the purpose. The boiler pressure against the head of the plug forces it to its seat. Because of its shape the plug is stronger than the ordinary handhole cover. It eliminates the necessity of a yoke, bolt, and nut, and also avoids the use of a gasket, which very often blows out and causes trouble. As the head

of the plug is circular, it cannot be put in from the outside through the circular opening that it closes. Instead, *master handholes,* as shown in Fig. 52, are provided in the bottom of the headers, through which the tapered plug is inserted and

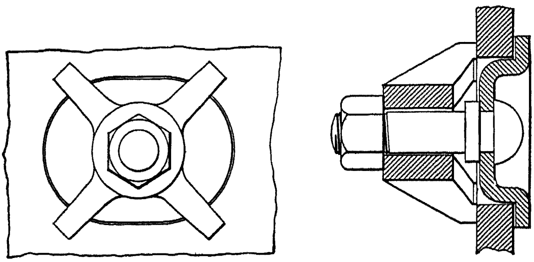


FIG. 52

then placed in the circular opening. When a handhole opening exceeds 6 inches in any dimension, the metal around the opening must be reinforced by a steel ring or liner.

MANHOLES

55. In general, the construction of a manhole and its cover does not differ materially from that of a handhole and its cover, except that the former is larger, being 10 in. by 14 in., 11 in. by 15 in., or 12 in. by 16 in. The usual size is 11 inches by 15 inches. A manhole should be cut in a boiler shell with the long diameter, or long axis, parallel to the girth seam,

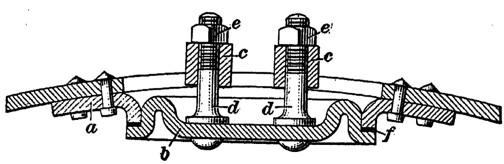


FIG. 53

because the stress per inch of girth seam is only half as great as the stress per inch of longitudinal seam. As the shell is materially weakened by cutting such a large hole, it is necessary to reinforce the plate around the manhole opening. The general practice in reinforcing manholes in shell boilers is to

rivet a reinforcing plate or a flanged ring *a*, Fig. 53, on the inside of the shell plate. The cover-plate *b* is held in position by two crabs *c* and the bolts *d* and nuts *e*. A gasket *f* is employed to obtain a steam-tight joint. The formation of the saddle or reinforcing ring is illustrated in Fig. 54; the plan view indicates the shape of the elliptical opening *a* and the width of the flange *b*, and the sections show the form of the flanges *b* and *d*. The flange *b* is turned to fit the curvature of the shell, and the flange *d* is straight across the face *e* to furnish a seat for the cover.

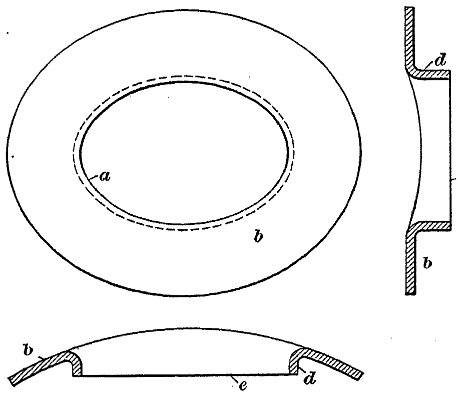


FIG. 54

56. In the perspective, Fig. 55, is shown an assembly of a manhole plate, reinforcing ring, and crab made of pressed steel. It will be noticed that only one crab is employed, thus making a light form of manhole cover installation. When a manhole is placed in a head, the sheet is usually flanged inwards, the flange serving to stiffen the metal around the opening. A flat manhole cover and other details for attaching the cover-plate in position are made like those already described. The manhole plates may be made of wrought steel or steel castings; cast iron is not suitable for pressure vessels. The least width of bearing surface for a manhole gasket is $\frac{1}{2}$ inch and the gasket should not be over $\frac{1}{4}$ inch thick.

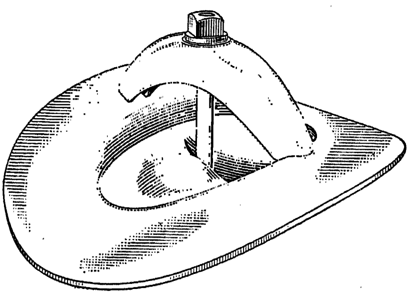


FIG. 55

WATER AND STEAM-PIPE OPENINGS

57. Reinforcement of Pipe Openings.—If water pipes or steam pipes that enter the head, shell, dome, etc., of a boiler are rather small and the plate is relatively thick, they may be screwed directly into the plate; but if such pipes are comparatively large, the plate must be reinforced where the pipes enter. The manner in which plates are reinforced at pipe openings depends somewhat on the size of the pipe and the thickness of the plate, and, in case a boiler fitting is attached, on the character of the fitting. The respective boiler rules specify how the pipe openings and other fitting connections should be reinforced. The A. S. M. E. Boiler Code contains the following requirements as to pipe connections to boilers: "If the thickness of the material in the boiler is not sufficient to give the required number of threads in accordance with Table I, the opening shall be reinforced by a pressed-steel, cast-steel, or bronze-composition flange, or plate, so as to provide the thickness of plate for the required number of threads."

TABLE I

MINIMUM NUMBER OF PIPE THREADS FOR BOILER CONNECTIONS

Size of Pipe Connection Inches	Number of Threads per Inch	Minimum Number of Threads Required in Opening	Minimum Thickness of Material Required Inches
1 and $1\frac{1}{4}$	$11\frac{1}{2}$	4	.348
$1\frac{1}{2}$ and 2	$11\frac{1}{2}$	5	.435
$2\frac{1}{2}$ to 4	8	7	.875
$4\frac{1}{2}$ to 6	8	8	1.000
7 and 8	8	10	1.250
9 and 10	8	12	1.500
12	8	13	1.625

58. Reinforcing Small Pipe Openings.—Small openings that are to be tapped for pipes not exceeding $1\frac{1}{2}$ inches nominal diameter usually have the holes reinforced with a triangular liner *a*, Fig. 56, which is riveted to the inside of the shell plate

as shown. The sectional view is taken on the line *A A* of the front view.

In horizontal tubular boilers having the blow-off attached to the bottom of the rear course, the hole is reinforced by an outside circular liner *a*, Fig. 57, attached to the boiler sheet by several rivets; flanges of the form shown in Fig. 58 are also used extensively, being riveted to the shell and calked. Connections for feedwater piping are made in this manner. This form of flange permits the pipe to be screwed in from each side and in addition reinforces the metal around the opening. The minimum size of pipe and fittings for blow-off piping is 1 inch, and the maximum size is not over $2\frac{1}{2}$ inches in diameter. Brass or steel bushings *a*, Fig. 59, are used for attaching feedwater piping up to and including pipes $1\frac{1}{2}$ inches in size. The bushing is threaded on the outside at *b* so as to enter the threaded

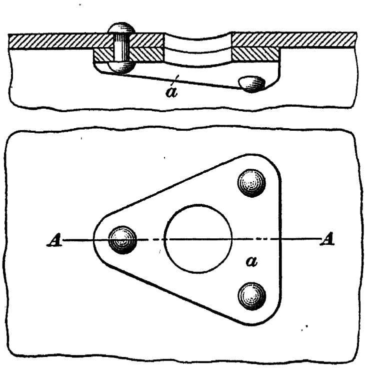


FIG. 56

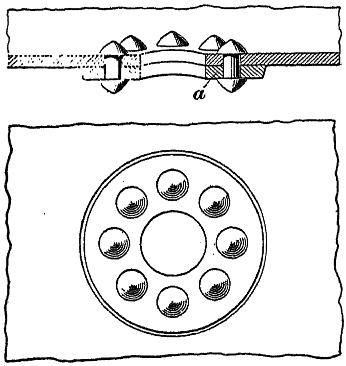


FIG. 57

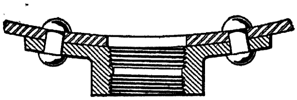


FIG. 58

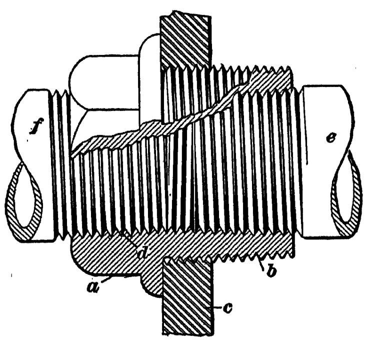


FIG. 59

opening in the plate *c*. The internal thread *d* permits turning the feed-pipes *e* and *f* into position. In tubular boilers, bushings of this kind are used extensively, being secured to the front head of the boiler and calked to prevent any possibility of leakage.

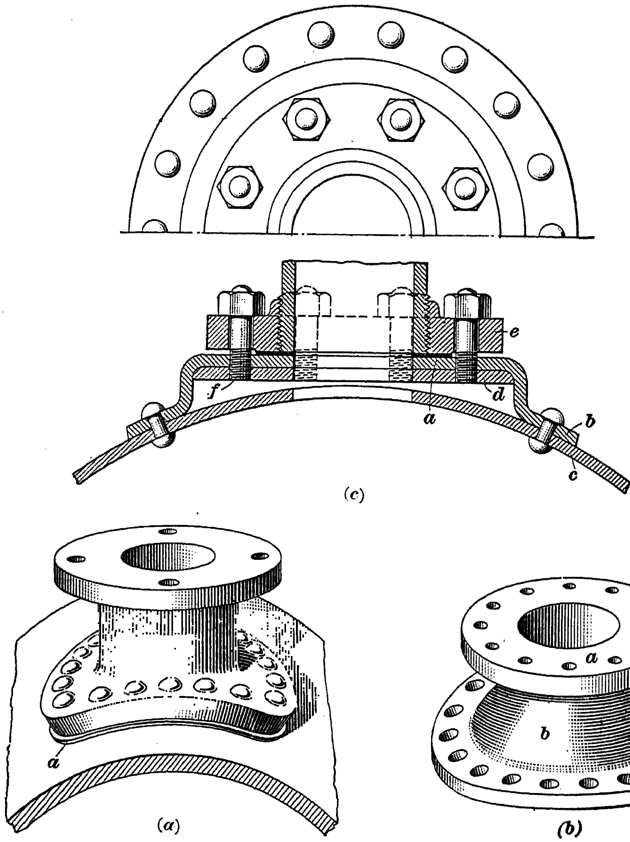


FIG. 60

59. Boiler Nozzles.—For openings $2\frac{1}{2}$ inches in diameter and larger it is necessary to use flanged fittings called *nozzles*. Such fittings are made of steel or iron castings of the form shown in Fig. 60 (*a*), or of pressed steel of the form shown in (*b*). The latter construction is the stronger and is best

suited for boiler-fitting connections. If cast steel or iron nozzles are used, the requirements governing their use and manufacture must be complied with. The A. S. M. E. Boiler Code does not permit the use of cast-iron fittings for pressure parts over 2 inches in diameter, for pressures above 160 pounds per square inch. For fittings of this kind up to and including 160 pounds per square inch, the nozzles must conform to the American Manufacturers' standard, except that in the case of nozzles for safety valves the face of the safety valve and nozzle may be made flat. In some cases the flange faces are made with a raised face that is machined to provide a straight bearing surface between the connecting fittings. Some authorities prohibit the use of cast iron for this purpose, owing to its low tensile strength and its liability to be in a weakened condition due to a porous formation of the metal in molding.

60. Pressed-steel nozzles, also referred to as saddle flanges, are made of the shapes shown in Fig. 60 (*b*) and (*c*). In either form the nozzle is pressed from steel plate to form the face *a* for the seat of the connecting fitting and the base *b* to conform to the shape of the boiler shell *c*. This form of construction produces a very strong fitting. The saddle shown in (*c*) is reinforced with a liner *d* of the same plate thickness, which is usually welded at four points to the saddle. To hold the pipe flange *e*, studs *f* are screwed into the plate *d* and the metal of the saddle. Both types of nozzles are beveled so that they can be calked. In the case of a cast nozzle, as in (*a*), a copper or steel strip *a* is placed between the nozzle and the plate for calking purposes.

BOILER DETAILS
(PART 2)

STAYING

TYPES OF STAYS AND BRACES

PURPOSE AND CLASSIFICATION

1. Introduction.—The terms *stay* and *brace* are applied to boiler details designed to support plates not strong enough in themselves to resist safely the steam pressure that the boiler is intended to carry. A stay or brace may be in tension or in compression, depending on the method of installation. Cylindrical shells, hemispherical heads, and spherical shapes subjected to internal pressure are self-supporting, as the pressure tends to maintain the curved forms; therefore, boiler plates of such forms and of sufficient thickness need no staying. Curved sections that cannot be made thick enough to sustain the steam pressure must be stayed.

Internal or external pressure acting on a flat plate tends to distort the metal to a spherical form; hence, a flat plate is not self-supporting, as it cannot be made sufficiently thick to prevent undue deformation. It is advantageous to use light boiler plate and stay it to withstand safely the given pressure.

2. Classification of Stays.—Stays used for bracing steam boilers may be divided into three general classes; namely, *direct stays, diagonal stays,* and *girder stays.*

A direct stay is one in which the load due to the steam pressure is applied directly in line with the axis of the stay. In

case the stay braces a flat surface, it will make an angle of 90 degrees with that surface; and if it is applied to a curved surface, it will be normal to it at the point of application. By *normal* is meant that the stay is at right angles to a straight line tangent to the surface at the point of application. A diagonal stay is a stay that is not placed at right angles to the surface it supports. A girder stay is a stay in the form of a girder, and is subjected to bending stresses produced by the load.

TYPES OF DIRECT STAYS

3. Solid Screw Staybolt.—A common form of solid screw staybolt, which is used for bracing in the small water spaces of locomotive-type and vertical boilers, is shown in Fig. 1. The staybolt, which is threaded for its entire length, is screwed into place, after which the ends are riveted over. The thread employed for screw stays is the United States standard, or 12 threads per inch.

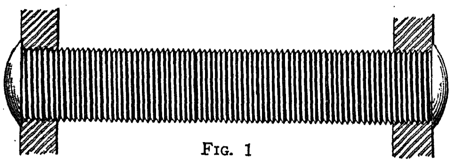


FIG. 1

4. Screw Staybolt With Telltale Hole. An improved form of screw staybolt used extensively for staying flat plates and internal fireboxes of vertical fire-tube boilers is shown in Fig. 2 (*a*). Only the ends are threaded, leaving the body of the stay smooth, as a smooth surface is not attacked so readily as a threaded surface by the corrosive elements of the feedwater. A hole *a*, called a *telltale hole*, is drilled into one or both ends of the staybolt, this hole having a diameter of from $\frac{3}{16}$ inch to $\frac{1}{4}$ inch and a depth of from 1 inch to $1\frac{1}{4}$ inches. When such a staybolt breaks, which, in locomotive-type boilers, occurs near the outside sheet, water or steam escaping through the crack and the hole *a*, as shown in (*b*), gives warning of the break. Many engineers prefer to have the telltale hole extended through the entire length of the staybolt, as shown in Fig. 3. A staybolt with a hole extending from end to end is called a *hollow staybolt*.

5. Screw Staybolts With Nuts.—In the Scotch type of marine boilers, the sides and back of the combustion chambers

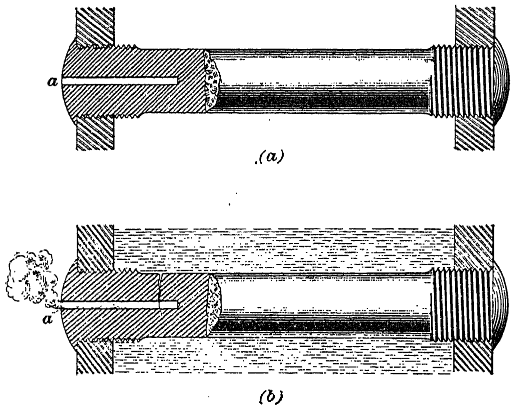


FIG. 2

are generally braced with screw staybolts, fitted with nuts, as shown in Fig. 4. The staybolt *a* is screwed into the plates *b* and has, on the outside of the plates, nuts forming heads. One of the nuts is shown enlarged at the left of the illustration. It has a recess *c*

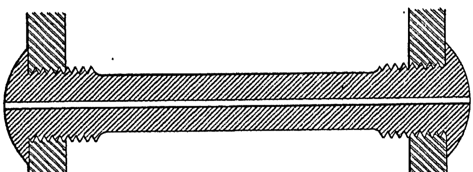


FIG. 3

in its face, which, before the nut is applied to the stay, is filled with stiff red-lead putty mixed with iron filings; this mix-

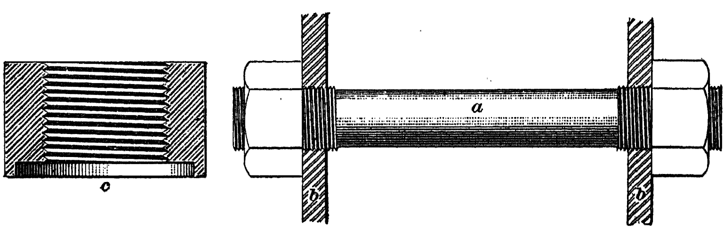


FIG. 4

ture aids in making a tight joint. If nuts are applied to staybolts used in stationary and locomotive work, they are put

on without any mixture or preparation; but in marine work, it is the usual practice to calk the sheets around the body of the bolt before applying the nuts.

6. Through Stays.—A long stay passing through the boiler from head to head is called a *through stay,* a *stayrod,* or

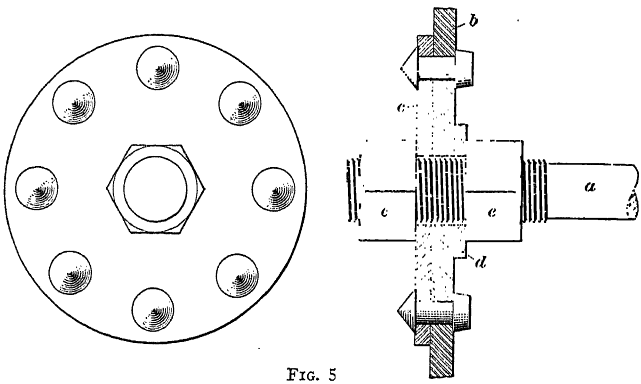


FIG. 5

an *end-to-end stay.* A common construction of one end of a stayrod is shown in Fig. 5. The end of the stayrod *a* is enlarged and threaded, and passes through a hole in the plate *b,* the hole being slightly larger than the threaded end of the stay-

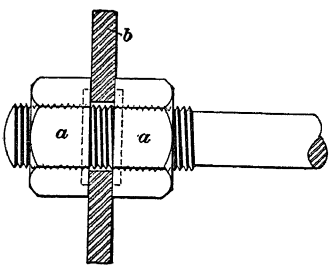


FIG. 6

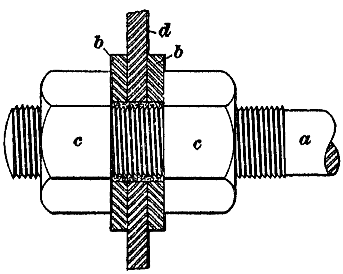


FIG. 7

rod. A large washer *c* is placed on the outside of the plate *b* and riveted to it, thus strengthening the head. A small washer *d* is usually placed on the inside. Nuts *e* lock the stayrod to the plate. Instead of using a large washer for each stayrod, a *stiffening plate,* often called a *doubling plate,* is used. This plate

covers the whole area of that part of the head braced by the stayrods and is riveted to either the inside or the outside of the head.

7. Washers are not always used under the nuts of the stayrod; when they are not used, the nuts bear directly against the plate, as shown in Fig. 6. The nuts *a* are recessed like those in Fig. 4, and the recesses are filled with the mixture described, or are packed with asbestos rope packing, so as to make a steam-tight joint against both sides of the boiler head *b*, Fig. 6.

8. Occasionally, the construction shown in Fig. 7 is adopted. The stayrod *a* is supplied with two washers *b* and two nuts *c*, which are not recessed. A steam-tight joint is made by filling the space between the head *d* and the hole of the washers and the threads of the stayrod with asbestos rope packing. Sometimes, as shown in Fig. 8, the stayrod *a* is screwed into the head *b* and locked by a nut *c* placed on the outside of the head.

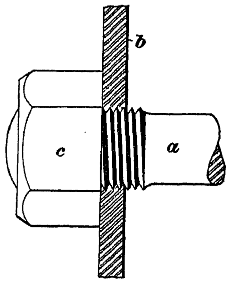


FIG. 8

9. Through stays are also made in other ways. In Fig. 9 (*a*) is shown a stay having one end *a* threaded and screwed into the tube-sheet *b*. At the other end *c*, the stay is formed with an eye. To fasten the eye end of the rod in place, angles *d* are riveted to the boiler head and the rod is then slipped between the angles and held in place by the bolt *e*. Another method of connecting the ends of stayrods to boiler heads is shown in (*b*). The end of the stayrod *a* is formed with a fork *b* to receive the forged leg connection *c*. Each leg *c* has a flat foot *d* that can be riveted to the tube-sheet. The combined sectional area of the two legs should exceed the cross-sectional area of the stayrod *a*. Forged connections of this type are used very often to support the tube-sheets of Scotch boilers.

10. Flexible Staybolts.—Rigid staybolts screwed into the furnace sheet and the outside sheet of a boiler are subjected not

only to tension but also to bending as the result of repeated expansion and contraction of the boiler plate. To overcome the breakage caused by this bending, flexible staybolts have been designed. There are two principal forms of the screw type, as shown in Fig. 10 (*a*) and (*b*). The standard screw type shown in (*a*) is used extensively in the water legs of locomotive boilers. The inner end *a* of the staybolt is threaded and screwed into the firebox sheet *b*. The head *c* of the outer end is partly

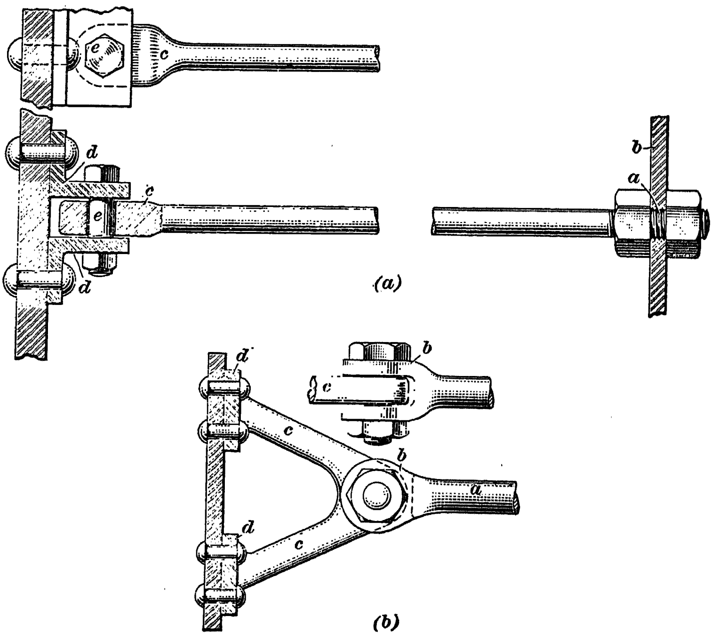


FIG. 9

spherical and fits a spherical seat in the sleeve *d*, which is screwed into the outside sheet *e*. The sleeve *d* is enlarged on the inside at *f* to permit the stay *a* to move freely in accommodating itself to the movement of the firebox sheets. A cap nut *g* is screwed over the sleeve to make a steam-tight joint. After the stay has been screwed in place, the threaded end is headed, as shown, and during the riveting process a bar with a spherical recess is held against the opposite end.

The flush type of flexible staybolt, shown in (*b*), is used in places where the projecting head, like that shown in (*a*), would interfere with setting other connecting parts. The construction of the bolt *a* shown in (*b*) is the same as the one shown in (*a*), except that it is shorter. The sleeve *b*, view (*b*), is screwed into the outer sheet *c* until it is flush with the outer surface. The plug *d* is screwed into the sleeve to produce a steam-tight connection.

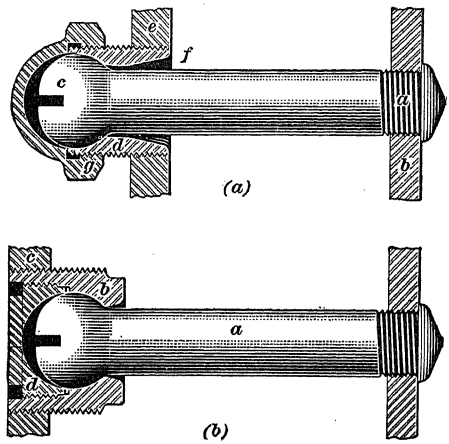


FIG. 10

11. Stay-Tubes. Many authorities require the flue sheets of large high-pressure boilers to be braced so that very little stress will come on the boiler tubes, which are expanded in place. In such a case, flue sheets are braced by using stay-tubes, which are tubes that act as end-to-end stays. Two methods of securing such stays to the tube-sheets are shown in Fig. 11 (*a*) and

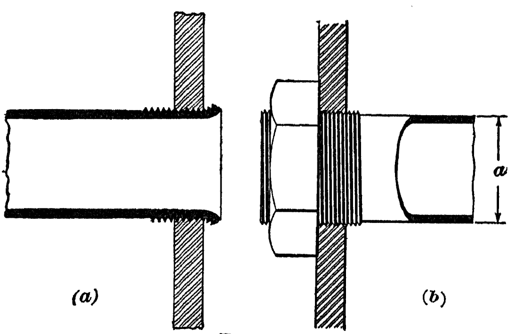


FIG. 11

(*b*). The ends of the tubes in both types are threaded and screwed into the tube-sheets. When the end is flared, as shown in (*a*), it should project beyond the tube-sheet $\frac{1}{4}$ inch. Stay-

tubes when threaded must not be less than $\frac{3}{16}$ inch thick, measured at the bottom of the thread. The body of the tube is made about $\frac{1}{4}$ inch smaller than at the threaded end, so that after the threaded end has been screwed through the first sheet, the tube can be easily shifted to install it in the second sheet, and then both ends can be screwed into the tube-sheets at the same time. In the construction shown in (*b*), a nut is screwed over the end of the tube, to bear against the tube-sheet. Nuts on stay-tubes are not advised where such tubes are used in staying the heads of tubular boilers, because the heat will burn the nuts away.

DIAGONAL STAYS

12. Radial Stays.—In locomotive boilers, the shape of the firebox and the outside furnace sheet is often such that it is

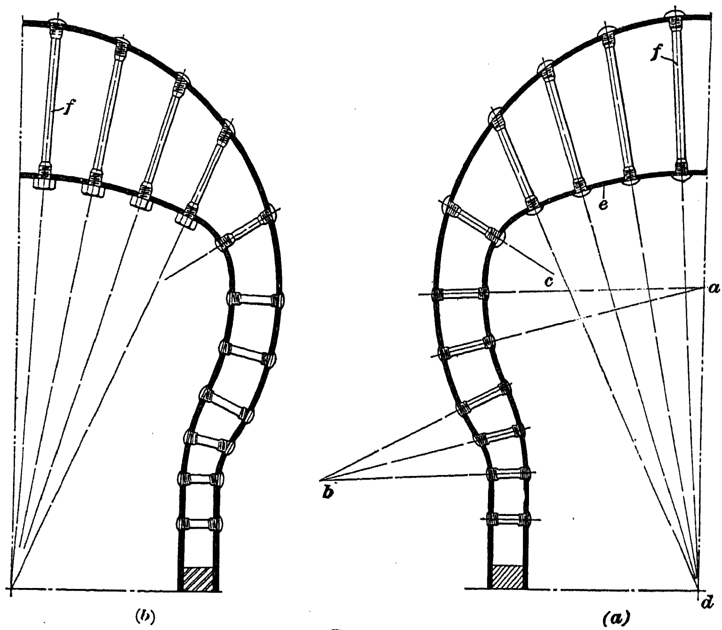


FIG. 12

convenient to brace the entire firebox with screw stays, arranged as shown in Fig. 12 (*a*). It will be noticed that various groups

of stays in the curved surfaces radiate from common centers, as *a, b,* and *d.* It is customary to apply the term *radial stays* to the stays that radiate from the center *d* and brace the crown sheet *e.* A locomotive boiler having radial stays for the crown sheet is a radial-type locomotive boiler. All staybolts of locomotive boilers are generally made with enlarged threaded ends and are screwed into the sheets. The radial stays are sometimes simply riveted over at both ends, as shown in (*a*), but it is also common to make the radial stays with a hexagonal head at the firebox end, as shown in (*b*). Staybolts supporting a crown sheet and having a head or a nut on the firebox end are

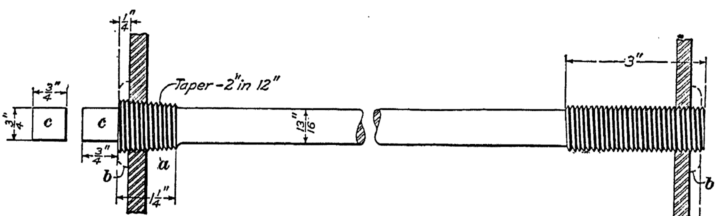


FIG. 13

often called *crown bolts.* The diameter of the body *f* of the stay should be made slightly less than the diameter at the root of the thread.

13. A standard crown stay of the dimensions now used for some locomotive boilers is shown in Fig. 13. The reduction of diameter of the stay between the threaded ends, effected by upsetting the ends for the smaller sizes and machining those of greater lengths, relieves to a certain extent the bending action due to the expansion and contraction of the sheets. This construction assists also in reducing the breakage of the stays, as the smoothness and flexibility of the stay lessen the accumulation of scale around it. The taper head *a* assists in assuring a steam-tight joint and a greater thread area to resist the pressure. Each end has twelve threads per inch and is upset so that a head $\frac{1}{4}$ inch in depth is obtained, as shown at *b.* The square head *c* is used for turning the stay into place, after which it is burned off with a gas torch.

14. The firebox ends of some crown stays are formed as shown in Fig. 14. The stay shown in (*a*) is an ordinary screw

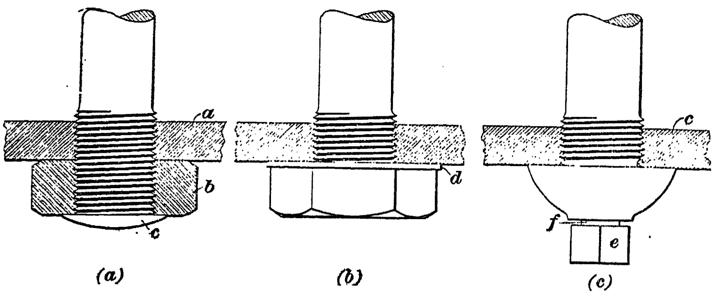


FIG. 14

stay screwed into the crown sheet *a*. When set in place the nut *b* is screwed tight against the crown sheet, and the end of

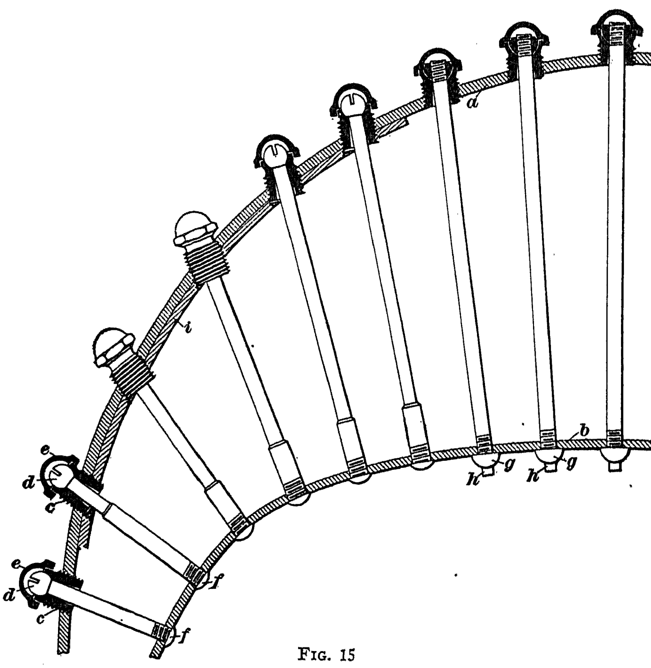


FIG. 15

the bolt is then riveted over as at *c* to retain the nut *b* in place. The crown bolt shown in (*b*) has a solid hexagonal head

forged on it and is screwed into the crown sheet. In order to make a steam-tight joint, a soft steel or copper washer *d* is usually placed under the head. In (*c*) is illustrated a button-headed crown bolt, which is provided with a square head *e* in addition to the button head. The square head is for the purpose of screwing the bolt tightly into the crown sheet *c*, after which it is removed. This may be done by nicking the groove *f* with a sharp chisel and then twisting off the head; or, the head may be burned off with a gas torch, the latter method being preferred. When crown bolts with nuts are used, as shown in (*a*), it is the practice of some boilermakers to calk the crown sheet to the bolts, on the fire side, before applying the nuts.

15. Flexible Radial Crown Stays.—In Fig. 15 are shown some of the different forms of flexible stays used for supporting the roof sheet *a* and crown sheet *b*. The sleeve *c*, spherical head *d* and cap *e* are similar to those in Fig. 10. The radial stays are headed over at the crown sheet, as shown at *f*, Fig. 15, the smaller head *f* being preferred to the button head *g*, as the larger body of metal of the button head burns away under the direct action of the heat from the fire. The square shank *h* of the button head is removed after the stay is in position. A roof liner *i* is attached to the roof sheet and the additional plate thickness provides a greater bearing area for the screw threads of the sleeves.

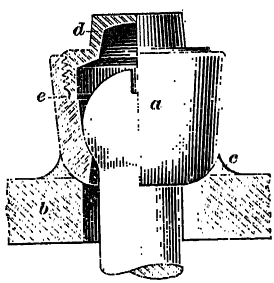


FIG. 16

The sleeve and cap shown in Fig. 16 are now being used extensively and are preferred by most engineers in place of the screw sleeves shown in Fig. 15. The cap *a*, Fig. 16, is welded to the roof sheet *b* by a light bead *c* and is closed by a cap *d* that is screwed down on a gasket in the recess *e*. The sleeve can be readily attached to a roof sheet of any curvature.

16. Gusset Stays.—A gusset stay, as shown in Fig. 17, consists of a steel plate *a* secured to the boiler head *b* and the shell *c* by angles *d*; or, tee irons may be used instead of angles.

This form of stay is used in bracing boiler heads of internally fired boilers, but the rigidity of the stay is objectionable as it

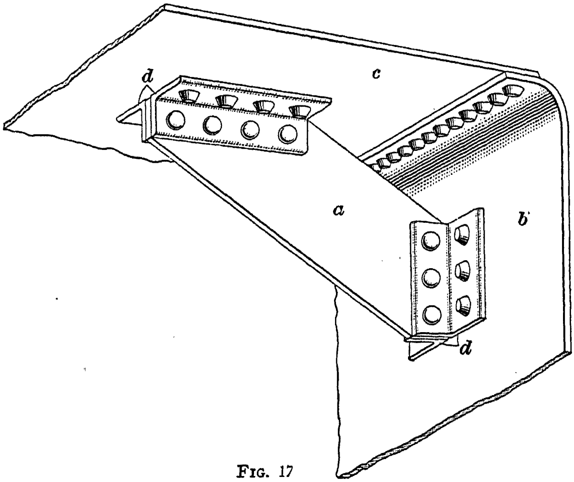


FIG. 17

localizes the stresses on the connecting boiler plates. With the construction shown, the rivets in the ends of the gusset are in double shear; but if a tee iron is used instead of the pair of angles, the rivets at the connection with the gusset will be in single shear. When tees or angles are used to connect diagonal braces to heads, they should be placed as shown in Fig. 18, in lines radiating from the center of the head.

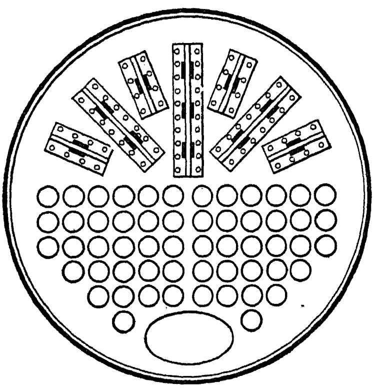
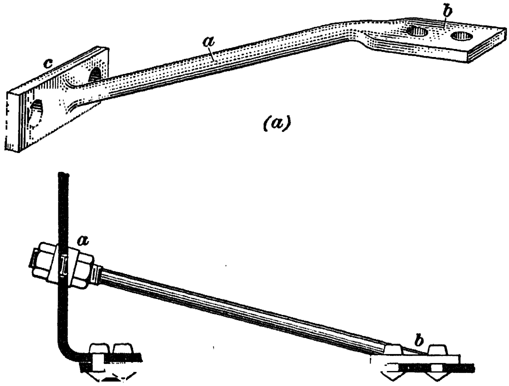


FIG. 18

17. Diagonal Stays. That part of a tube-sheet that does not receive support from tubes—as, for example, the segment of a flat head above the upper row of tubes in a tubular boiler—must be stayed. A common form of stay used for this purpose is the diagonal stay. It may consist of a rod welded at the ends to flat pads that are riveted to the head and

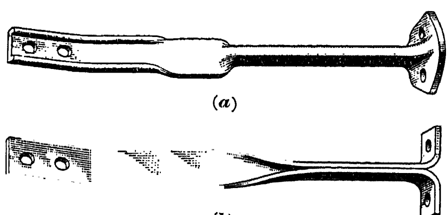
the shell; or, it may be made from a solid strip of boiler plate formed to the desired shape under hydraulic pressure. The lat-



(b)

FIG. 19

ter type is considered more reliable than the welded type. A form of welded brace is shown in Fig. 19 (*a*). The wrought-iron rod *a* is welded at one end to the flat pad, or palm, *b* by which the stay is connected to the shell plate, and at the other end to a pad *c* that is riveted to the tube-sheet segment or boiler head. This form is frequently called the *palm stay*. Another form of welded stay is shown in (*b*). The end *a* is enlarged and threaded and passes through a still larger hole in the boiler head. Wedge-shaped washers fit against opposite sides of the plate and are set up tightly by means of the nuts. The palm end *b* is riveted to the shell. This form of stay is not used extensively because of the difficulty of maintaining a steam-tight connection at the end *a*.



(b)

FIG. 20

18. The weldless forms of diagonal braces shown in Fig. 20 (*a*) and (*b*) are an improvement over the welded types previously described. The brace shown in (*a*) is the McGregor weldless brace. It is

made in one operation by heating a piece of sheet steel, splitting one end to form the crowfoot, and bending the other to the desired angle, all under heavy pressure. Because of the manner in which the branches at the end are split and bent outwards, this type of brace is frequently termed a *crowfoot brace*. Another form of diagonal stay, known as the Huston crowfoot brace, is shown in (*b*). The body of the brace is doubled, thus enabling the foot to be made solid, without splitting. The palm end is formed to a channel shape, producing a strong brace.

GIRDER STAYS

19. Girder Stays in Scotch Boilers.—The tops of the combustion chambers of Scotch boilers are usually supported by girder stays, also called *crown bars*. In Fig. 21 is shown how

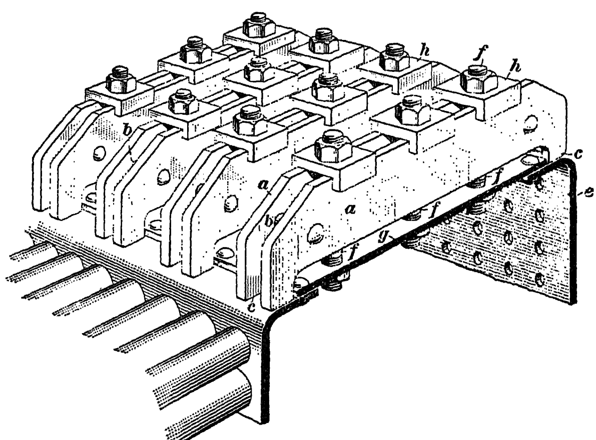


FIG. 21

girder stays are arranged over the top of a combustion chamber. Each girder consists of two steel plates *a* of the same shape and thickness, set side by side and held at a fixed distance from each other by thimbles *b* through which pass rivets that hold the plates *a* together. This built-up girder is placed on top of the combustion chamber, with its ends *c* resting on the upper

ends of the heads *d* and *e* of the combustion chamber. Bolts *f*, threaded at both ends and fitted with nuts, are inserted through holes in the crown sheet *g* that is to be supported. These bolts fit between the plates *a* and at their upper ends pass through clips *h* having lugs that fit over the plates *a* and help to prevent their spreading. The nuts on the bolts are tightened, and thus the pressure of the steam on top of the plate *g* is transmitted by the bolts to the girder, and by it to the plates *d* and *e*, which carry the entire load. Girders of this type are spaced at uniform intervals across the top of the combustion chamber.

20. A different form of girder stay is shown in Fig. 22. The girder itself is composed of two plates held apart by spools, or distance pieces, and the bolts that support the crown sheet fit between the girder plates as in the type just described. But the load is not carried by the combustion-chamber heads. Instead, stays *a* are attached at the ends of the girder, between its plates, and the upper ends of these stays are connected to angle irons *b* riveted to the inside of the top sheet of the boiler. Thus, the load due to the downward pressure on top of the crown sheet is carried by the outer shell, from which the girders are suspended by the stays *a*.

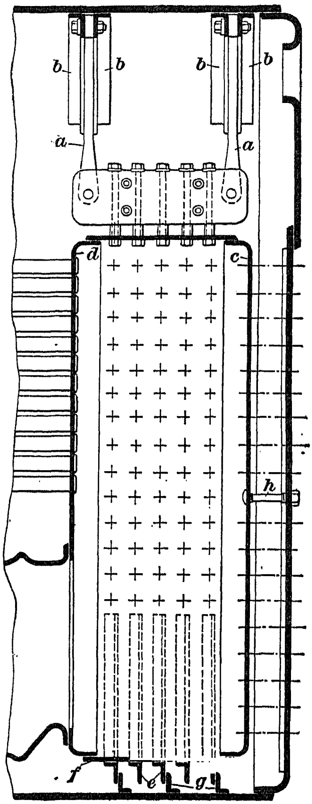
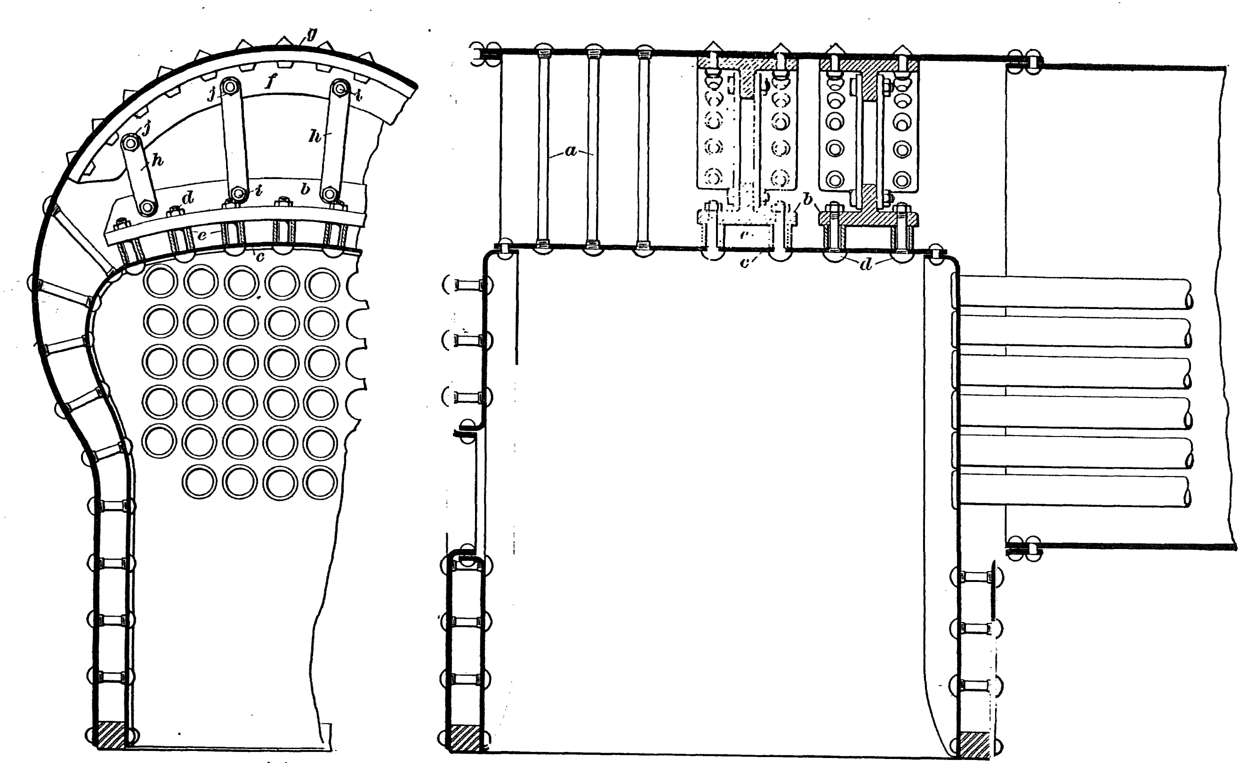


Fig. 22

As the plates *c* and *d* are thus relieved of the load, they need not be so heavy as when a girder of the form shown in Fig. 21 is used. The bottom of the combustion chamber, Fig. 22, is braced by angle irons *e* riveted to the bottom plate *f*. Alternate angle braces are connected to angles *g* riveted to the boiler



(a) (b)

FIG. 23

shell. In some constructions, screw stays are employed for staying the bottom sheets. The sides of the combustion chamber are stayed by screw stays *h* that may be riveted over at the ends; or, they may be riveted over on the ends inside the combustion chamber and have nuts on the outside.

21. Locomotive-Boiler Crown Bars.—In some types of locomotive boilers the crown sheets and side sheets are so arranged and shaped that there are no projecting sections, as in Fig. 21, on which to set the ends of the girder stays. An example of this kind is shown in Fig. 23 (*a*) and (*b*). The usual practice in staying such a firebox is to install radial stays *a*, or crown bolts, and at the forward end two crown bars *b*, bent to the curvature of the crown sheet *c*. Usually the crown bars are made of structural forms, such as tee irons. The crown bar *b* is attached to the crown sheet by means of crown bolts *d* that pass through the flanges of the crown bar and through spools *e* inserted between the crown sheet and the crown bar.

The roof bar *f* is a tee iron bent to conform to the curvature of the roof sheet *g* to which it is riveted. Flat steel-plate stays *h* called *sling stays*, connect the roof bar *f* and the crown bar *b*. The brace pins *i* are threaded and are inserted into holes in the stays and tees. The nuts *j* that hold the pins *i* in place are prevented from turning off by cotter pins through the ends of the brace pins. The hole in the lower end of each sling stay is made oblong for the following reason: As the radial screw stays *a* are rigidly fixed and as the crown sheet is rigidly supported by the flange of the tube-sheet, the unequal expansion and contraction of the crown sheet causes a bending action on the stays. To overcome this condition it is customary to use a sling stay having an oblong hole, as this allows the outer plates of the firebox to contract without placing any great bending load on the sling stays.

MISCELLANEOUS BRACES

22. Throat Braces.—In boilers of the locomotive type the firebox tube-sheet must be braced below the tubes. In some constructions this can be done satisfactorily by ordinary screw

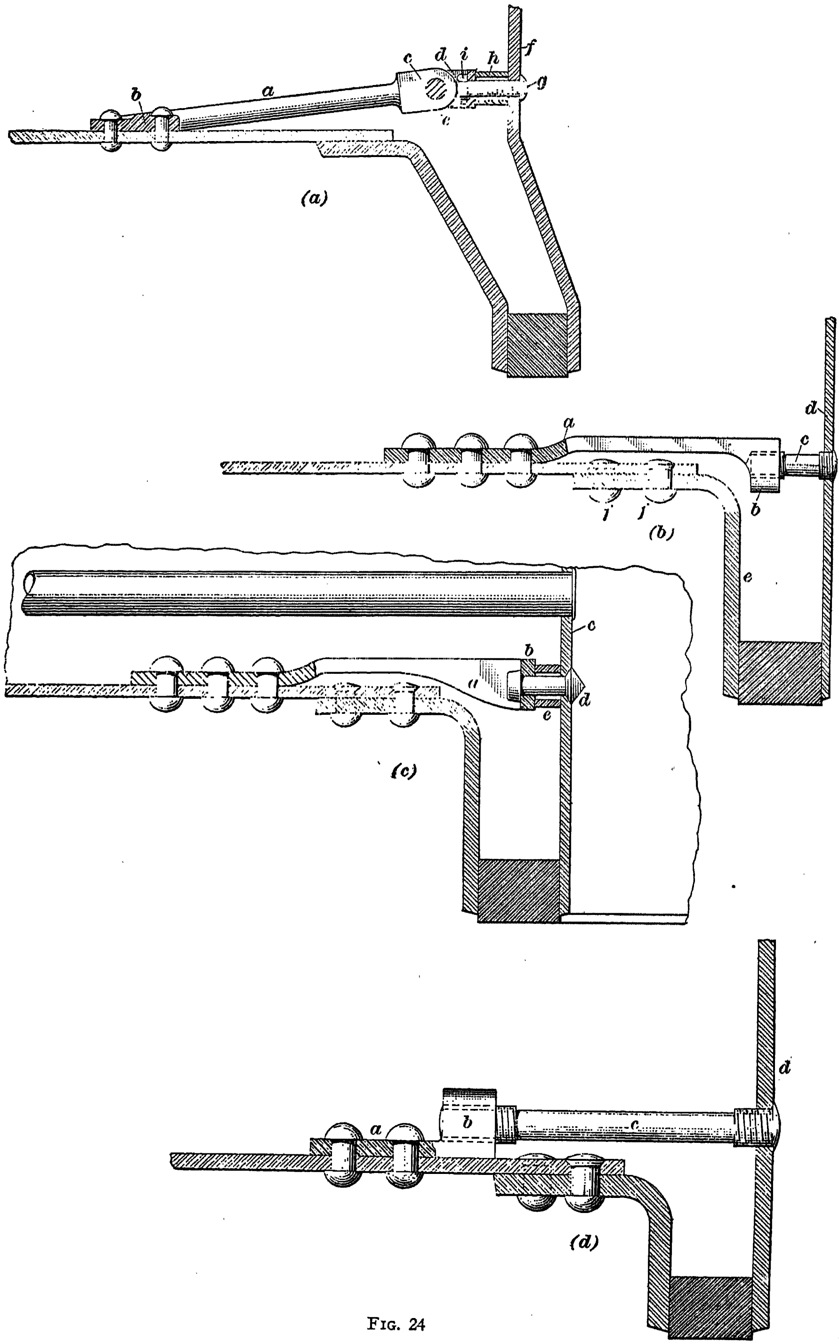


FIG. 24

staybolts; but where the arrangement of the firebox sheets is such that the tube-sheet extends beyond the throat sheet, special forms of stays are used to stay the tube-sheet to the boiler shell. The stays employed for this purpose are called *throat braces*, or *heel braces*. Several types of throat braces are shown in Fig. 24. The brace *a* shown in (*a*) is made with a palm *b* that is riveted to the boiler shell, and the other end is formed into a fork *c* that is attached to a crowfoot *d* by means of the brace pin *e*. The crowfoot *d* is fastened to the tube-sheet *f* by two stays *g* that pass through distance pieces *h*. The end of the staybolt passing through the crowfoot is made usually with a hexagon head *i*.

23. The throat brace shown in Fig. 24 (*b*) is a steel drop forging bent at *a* to clear the rivet seam between the boiler shell and the throat sheet. The end of the stay that is riveted to the shell is flat and the other is upset to form a projecting end or boss *b*. The boss is drilled and tapped to receive the staybolt *c*, which is screwed into the tube-sheet *d* and riveted over. The throat sheet *e* is made somewhat thicker than the sheet *d*. In order that the brace need not have too large an offset, which would introduce transverse stresses and affect its staying qualities, it is customary to use countersunk rivets *f* in the throat seam under the brace.

A modification of the brace in (*b*) is shown in (*c*). In this type the brace *a* is made with a crowfoot *b* that is riveted to the tube sheet *c* by rivets *d* passing through distance pieces. The distance pieces allow a larger water space between the tube-sheet and the crowfoot. The rivet holes in the tube-sheet are usually countersunk so that only a small amount of the rivet head projects into the firebox.

In the stay installation shown in (*d*), a threaded stay is employed. It produces a strong support and one that is readily applied. The lug *a* is a drop forging of steel and the projecting end *b* is drilled and threaded to receive the stay *c*. The stay is screwed into the tube-sheet and headed. Owing to its length the stay gives with the expansion and contraction of the firebox, which is a desirable feature.

24. Steel Angle Stays.—For the upper segments of tube heads of boiler shells not exceeding 36 inches in diameter, and when the boilers are designed to carry a working pressure not greater than 100 pounds per square inch, the method of bracing shown in Fig. 25 may be employed. The steel angles are placed back to back so that their short legs *a* can be riveted to

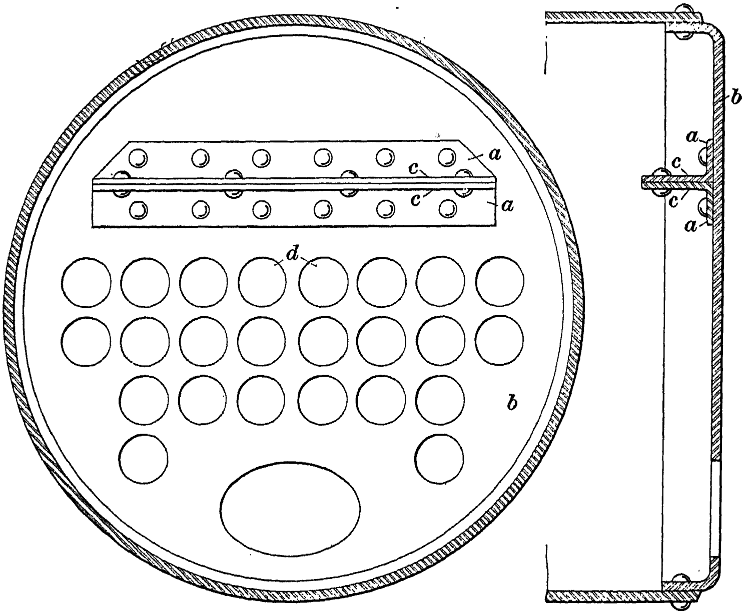


FIG. 25

the boiler head *b*. The projecting legs *c* of the angles are also riveted together. The spacing of the rivets in the legs *c* should not be over 8 inches and the spacing of the rivets attaching the angles to the boiler head should not be over 4 inches. The bottom of the lower angle should be not less than 2 inches above the top row of tubes *d*. Rivets of the same diameter as are used in the boiler shell should be used for this method of bracing.

TUBES, FLUES, AND FURNACES

BOILER TUBES AND FLUES

BOILER TUBES

25. Purpose of Boiler Tubes.—The principal purpose of boiler tubes is to increase the heating surface of the boiler and thereby increase its steaming capacity. The tubes also divide the water and heated gases into small bodies, which assists in the transmission of the heat from the fire to the water. When the tubes are expanded in the boiler heads, or tube-sheets, they act as stays to support the flat plates.

26. Manufacture of Boiler Tubes.—Boiler tubes may be made of iron, steel, brass, copper, or monel metal. Steel tubes may be either lap-welded or seamless. In making lap-welded tubes, strips of metal, or *skelps,* are prepared with scarfed edges, so that, when these edges are overlapped to form the welded seam, there will be no undue thickness of metal. The skelp is heated, and while hot is bent to a circular form through a die, after which it is reheated to a welding temperature. In the welding operation it is passed through or between rolls grooved to give it the desired tubular form. A mandrel inside the tube forms the anvil on which the overlapping scarfed edges are pressed firmly together to form the weld. After welding, the tubes are annealed to remove the internal stresses set up by heating, and working the metal during the welding process. Lap-welded charcoal-iron tubes are made in the same way by using charcoal-iron skelp.

27. Seamless tubes of steel and charcoal iron are used extensively in locomotive boilers, as both kinds withstand to good advantage the severe service arising in the operation of

locomotives. Seamless steel tubing is produced from a round steel billet that is placed in a furnace and heated to a white heat. The billet is then pushed by special machinery and at the same time pierced by a pointed mandrel, which produces a rough tube several times as long as the original billet. The next process consists in rolling the rough tube over a mandrel, whereby the thickness of the tube wall and the diameter are

TABLE I

DIMENSIONS AND WEIGHTS OF BOILER TUBES

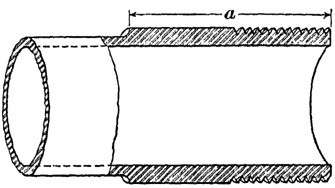
Outside Diameter Inches	Thickness of Wall		Theoretical Weight per Foot	Length of Tube in Feet per Square Foot of	
	Inch	B. W. G.	Pounds	External Surface	Internal Surface
1	.095	13	.918	3.820	4.715
1¼	.095	13	1.171	3.056	3.604
1½	.095	13	1.425	2.546	2.916
1¾	.095	13	1.679	2.182	2.448
2	.095	13	1.932	1.909	2.110
2¼	.095	13	2.186	1.697	1.854
2½	.109	12	2.783	1.527	1.673
2¾	.109	12	3.074	1.388	1.508
3	.109	12	3.365	1.273	1.373
3¼	.120	11	4.011	1.175	1.269
3½	.120	11	4.331	1.091	1.171
3¾	.120	11	4.652	1.018	1.088
4	.134	10	5.532	.954	1.023
4½	.134	10	6.248	.848	.902
5	.148	9	7.669	.763	.812

reduced and the rough tube is converted into a longer and smoother tube. The tubing is then passed through a burnishing machine to give it a smooth burnished surface, after which it is sized through finishing rolls that produce the required outside diameter. Tubes manufactured in this manner are known as *hot-rolled seamless tubes*. *Cold-drawn seamless tubes* are

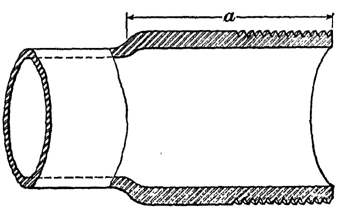
made in a similar manner, except that the metal is not reheated while being worked. Such tubes are annealed to insure ductility of the metal, so that they can be easily expanded, flared, and beaded without splitting the ends.

Brass and copper tubes for boilers are seamless; such tubing, however, is not used to any great extent in the United States and Canada. European countries use it in preference to steel and iron tubing, on account of the resistance of such metals to the corrosive effects of the feedwater.

28. Sizes and Gauges of Boiler Tubes.—The sizes of tubes are designated by their outside diameters to distinguish them from pipes, which are designated by their normal inside diameters. Tubes more than 6 inches in diameter are usually called *flues*. The thickness of tubes is generally expressed by giving the number of the corresponding notch of the Birmingham wire gauge, generally abbreviated to B. W. G. Table I gives the standard thickness of lap-welded and seamless-drawn boiler tubes, both by the wire gauge and in decimals of an inch, together with the minimum weight per foot of length and the length per square foot of surface. Boiler tubes in all sizes can be obtained one gauge number thicker than given in the table, for use in boilers carrying a very high working pressure. In estimating the effective heating surface of boiler tubes or flues, the surface in contact with the products of combustion is considered, whether internal, as in the case of fire-tubes, or external, as in the case of water-tubes.



(a)



(b)

FIG. 26

29. Upset Tubes.—Tubes known as upset tubes are produced by upsetting the tube ends, thus increasing the thickness of the wall at those points. Such tubes are used for stay-tubes,

TABLE II

DIMENSIONS OF BOILER TUBES WITH UPSET ENDS

Outside Diameter of Tube Inches	Thickness of Tube													
	B. W. G.							Inch						
	10	9	8	7	6	5	4	$\frac{1}{4}$	$\frac{9}{32}$	$\frac{5}{16}$	$\frac{11}{32}$	$\frac{3}{8}$	$\frac{13}{32}$	$\frac{7}{16}$
	Outside Diameter of Upset End, in Inches													
$1\frac{1}{2}$	1.63	1.65	1.67	1.69	1.70	1.72	1.74	1.75	1.78	1.81	1.84	1.88	1.91	1.94
$1\frac{3}{4}$	1.88	1.90	1.92	1.94	1.95	1.97	1.98	2.00	2.03	2.06	2.09	2.13	2.16	2.19
2	2.13	2.15	2.17	2.19	2.20	2.22	2.24	2.25	2.28	2.31	2.34	2.38	2.41	2.43
$2\frac{1}{4}$	2.38	2.40	2.42	2.44	2.45	2.47	2.49	2.50	2.53	2.56	2.59	2.63	2.66	2.69
$2\frac{1}{2}$	2.63	2.65	2.67	2.69	2.70	2.72	2.74	2.75	2.78	2.81	2.84	2.88	2.91	2.94
$2\frac{3}{4}$	2.88	2.90	2.92	2.94	2.95	2.97	2.98	3.00	3.03	3.06	3.09	3.13	3.16	3.19
3	3.13	3.15	3.17	3.19	3.20	3.22	3.24	3.25	3.28	3.31	3.34	3.38	3.41	3.44
$3\frac{1}{4}$	3.38	3.40	3.42	3.44	3.45	3.47	3.49	3.50	3.53	3.56	3.59	3.63	3.66	3.69
$3\frac{1}{2}$	3.63	3.65	3.67	3.69	3.70	3.72	3.74	3.75	3.78	3.81	3.84	3.88	3.91	3.94
$3\frac{3}{4}$	3.88	3.90	3.92	3.94	3.95	3.97	3.98	4.00	4.03	4.06	4.09	4.13	4.16	4.19
4	4.13	4.15	4.17	4.19	4.20	4.22	4.24	4.25	4.28	4.31	4.34	4.38	4.41	4.44
$4\frac{1}{4}$	4.38	4.40	4.42	4.44	4.45	4.47	4.49	4.50	4.53	4.56	4.59	4.63	4.66	......
$4\frac{1}{2}$	4.63	4.65	4.67	4.69	4.70	4.72	4.74	4.75	4.78	4.81	4.84	4.88	......	......
$4\frac{3}{4}$	4.88	4.90	4.92	4.94	4.95	4.97	4.98	5.00	5.03	5.06	5.09	......	......	......
5	5.13	5.15	5.17	5.19	5.20	5.22	5.24	5.25	5.28	5.31	......	......	......	......

which may be threaded at the ends and screwed into the tube-sheets; or, nuts may be placed on the threaded ends, on the outside and also inside of the tube-sheet. Upset tubes may also be used in place of ordinary boiler tubes. There are two general forms of upset tubes, which are shown in Fig. 26 (*a*) and (*b*). The type shown in (*a*) is the plain upset tube and that in (*b*) is the upset and swelled-end form. In either case the usual length of the upset *a* is $2\frac{1}{2}$ inches. There is a limit to the thickness to which the tube ends can be properly upset. Above this maximum it is difficult to upset the ends to a greater thickness. Table II gives the sizes of tubes and thicknesses of tube walls, with the corresponding outside diameters of the upset ends as ordinarily used.

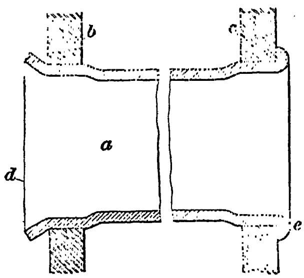


FIG. 27

30. Installation of Boiler Tubes.—The method of securing the fire-tubes in the heads of tubular boilers is shown in Fig. 27. The tube *a* is from $\frac{1}{32}$ to $\frac{1}{16}$ inch smaller in diameter than the tube holes in the tube-sheets *b* and *c*. This is essential so that the tubes can be readily put in place. Each tube end should project $\frac{1}{4}$ inch beyond the tube-sheet. When the tubes are in place, they are expanded by means of a tube expander, or tube roller. The projecting ends are then peened over, or flared, as shown

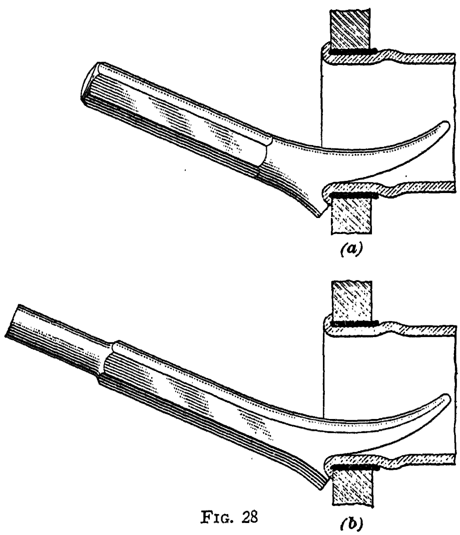


FIG. 28

at the end *d,* which may be done by using the ball end of the boilermaker's hammer, or with a flaring tool, which is tapering in form and operated by an air hammer. After the ends are flared, they are beaded, as shown at *c*, by the use of a beading tool, or *boot tool,* which is made as shown in Fig. 28 (*a*) for hand beading. For beading done by the use of an air hammer, a tool of the same shape is used, having at the end a circular shank, as shown in (*b*), which is inserted in the driving end of the air hammer. The beading tool should be held in about the position indicated so that the bead is brought down over the edge of the plate; otherwise, the bead may be forced away from the tube-sheet, resulting in leaky tubes.

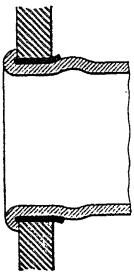


FIG. 29

31. In the installation of tubes in Scotch boilers, the tube *a,* Fig. 27, is inserted from the front head of the boiler. The ends of the tubes in the combustion chamber are set to project $\frac{1}{4}$ inch beyond the combustion-chamber tube-sheet, and at the front end from $\frac{1}{4}$ to $\frac{3}{8}$ inch outside the front head. Both ends are expanded and those in the combustion-chamber end are flared and beaded; but at the front end the tubes are usually expanded and flared. Stay-tubes having upset and threaded ends are extensively used in staying the heads of Scotch boilers.

Locomotive boiler tubes are installed in a similar manner except that a copper liner, or *ferrule,* is usually placed between the tube-sheet in the firebox and the tubes. Such liners take up the inequalities in the metal of the tube and plate, thus insuring a tighter connection. The ferrules are usually about $\frac{1}{16}$ inch thick and are set to extend about $\frac{1}{16}$ inch inside the hole from the tube-sheet, as shown in Fig. 29. It is also the practice to weld the bead of the tubes to the firebox tube-sheet to insure steam-tightness. Water tubes in water-tube boilers are expanded and flared.

BOILER FLUES

32. The purpose of boiler flues is identical with that of boiler tubes. In sizes from 6 inches to 16 inches, external diameter, they can be obtained lap-welded and of sufficient length. The larger sizes of flues are often made, however, with longitudinal lap joints or butt joints, and are constructed of short sections riveted together. The standard sizes of lap-welded boiler flues, minimum weight per foot of length, and length of flue per square foot of surface, together with their thickness by wire-gauge number and in decimals of an inch, are given in Table III.

TABLE III

PROPERTIES OF LAP-WELDED FLUES

Outside Diameter of Flue Inches	Thickness of Flue		Theoretical Weight per Foot Pounds	Length of Flue, in Feet, per Square Foot of	
	Inch	B. W. G.		External Surface	Internal Surface
6	.165	8	10.282	.636	.673
7	.165	8	12.044	.545	.572
8	.165	8	13.807	.477	.498
9	.180	7	16.955	.424	.442
10	.203	6	21.240	.381	.398
11	.220	5	25.329	.347	.361
12	.229	..	28.788	.318	.330
13	.238	4	32.439	.293	.304
14	.248	..	36.424	.272	.282
15	.259	3	40.775	.254	.263
16	.270	..	45.359	.238	.247

The standard thicknesses of boiler flues having an external diameter of 12, 14, and 16 inches, do not correspond to B. W. G. numbers, and hence are given only in decimals of an inch.

FURNACE FLUES AND COMBUSTION CHAMBER

CYLINDRICAL FURNACE FLUES

33. Plain Furnace Flue.—The simplest form of furnac flue is a plain cylinder of wrought-iron or steel plate, which ma have a riveted longitudinal seam or may be welded. If condi tions were such as to call for a comparatively large furnace flu and a high pressure, a plain furnace flue would have to be s thick as to interfere seriously with the transfer of heat fron the fire to the water. To overcome this defect, plain furnac flues are stiffened by means of strengthening rings, which ar attached to the outside, where they are in contact with th water in the boiler.

34. Furnace Flues With Strengthening Rings.—To strengthen the plain type of furnace flue, stiffening rings of

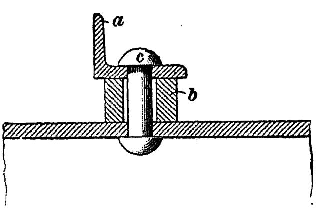


FIG. 30

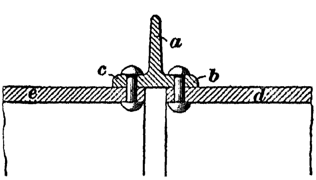


FIG. 31

angle iron or tee iron are attached to the outside. A common construction is shown in Fig. 30. The strengthening ring *a* is made of angle iron and encircles the flue, from which it is separated by a spool *b* placed around each rivet *c*. The spools hold the ring away from the flue and thus provide for a free circulation of water between them. The circulation of water next to the flue protects it from injury by the fire. A short furnace flue of a given diameter and thickness is much stronger than a long one of the same diameter and thickness; therefore, furnace flues are often made in sections united in such a manner as to secure great strength with comparatively thin material. Flues thus constructed are called *built-up furnace flues,* and also *sectional furnace flues*.

35. A simple method of constructing a built-up furnace flue, but one that is little used, is illustrated in Fig. 31. A welded **T**-iron ring *a* has its legs *b* and *c* riveted to the plain cylindrical sections *d* and *e* of the furnace flue. Although this construction is an improvement over that shown in Fig. 30, there are better forms in use for joining the sections, as, for instance, the *Adamson ring joint* shown in Fig. 32. When this type of ring joint is used, the ends *a* and *b* of the sections are flanged

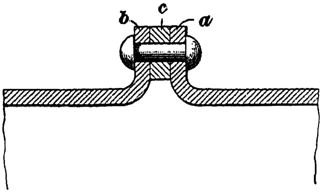


FIG. 32

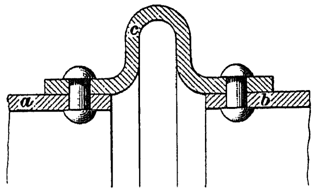


FIG. 33

and riveted together with a welded and finished ring *c* between them. The flanging provides stiffness to resist the external pressure, and the rounded corners of the flange allow for a little expansion and contraction. In Fig. 33 is shown a method of building a cylindrical furnace. The sections *a* and *b* are joined by a **U**-shaped ring *c*, called a *bowling ring*. This ring stiffens the plain cylindrical sections and at the same time, owing to its curvature allows for longitudinal expansion and contraction.

CORRUGATED FURNACES

36. Manufacture of Corrugated Furnaces.—There are several types of corrugated furnaces, commonly called *suspension furnaces*, that differ only in the shapes of their corrugations and their ends. The corrugations are produced in plain cylinders having welded longitudinal joints. Preparatory to being corrugated the cylinders are heated uniformly. They are then passed through rolls and the corrugations are formed under hydraulic pressure. When the forming process is complete, the shells are again heated to anneal them and relieve the stresses due to expansion and contraction of the metal. The corrugations strengthen the furnace, increase the heating surface, and

permit the furnace to expand and contract longitudinally, or in the direction of its length. Furnaces of this kind are made

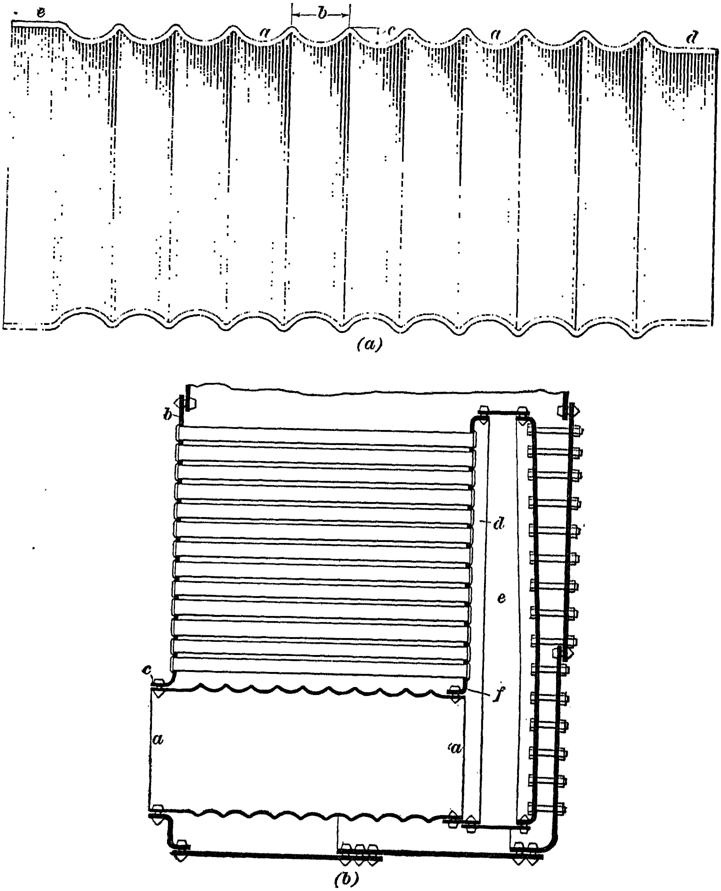


FIG. 34

from 28 to 60 inches in diameter, inside, and with a plate thickness of from $\frac{5}{16}$ to $\frac{3}{4}$ inch.

37. Morison Corrugated Furnaces.—In Fig. 34 (a) is illustrated the Morison suspension furnace. The curved sections a, called the corrugations, have a pitch b of 8 inches from center to center, the depth c of the corrugations being $1\frac{1}{2}$ inches.

This type of furnace is made with different forms of plain ends, to suit the requirements of design of the combustion chamber and furnace connections of Scotch boilers. The furnace is constructed with an inside end *d* and an outside end *e*. The end *d* would fit inside and the end *e* outside the flange connections of the boiler heads. There are two other forms of plain ends, one form of which has two ends of the inside type and the other form has two ends of the outside type. In view (*b*) is shown a furnace with two inside plain ends *a*, one of which is riveted to

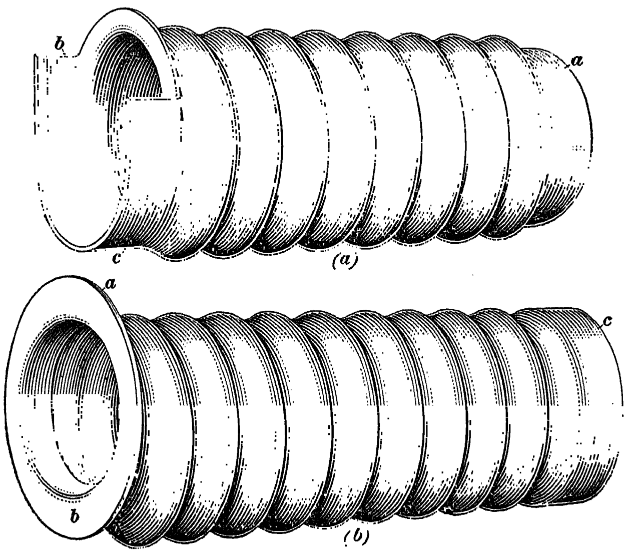


FIG. 35

the outer head *b*, which has the flange *c* turned out for installing the furnace. The head *d* of the combustion chamber *e* is also turned out, as shown at *f*. It will be seen from the construction that, in order to replace the furnace, it is necessary to remove the front head, as such a furnace cannot be taken out through the circular flanged opening in the front head. To overcome this condition, furnaces of a special type have been designed, so as to make the work of removal easy.

38. There are in general use two types of removable furnaces, which are of the forms shown in Fig. 35 (*a*) and (*b*).

The one shown in (*a*) has one plain inside end *a*, and the opposite end is cut away and flanged at *b*. The flanged portion extends only a short distance around the top of the furnace. The bottom section *c* is of the same shape as the end *a*. The other form, shown in (*b*), is known as the horse-collar type, on account of the shape of the oval end *a*, which in profile has the shape of a horse collar. The flange *b* is set flush against the side of the combustion-chamber head and riveted to it. The opposite end *c* is made of a plain circular form.

In replacing a furnace of the horse-collar type it is inserted into the front end of the boiler and raised off center, so as to give it a slant, thus allowing the upper flange *a* to slide inside the circular flange of the front head. After the furnace has been raised sufficiently so that the lower edge clears the bottom

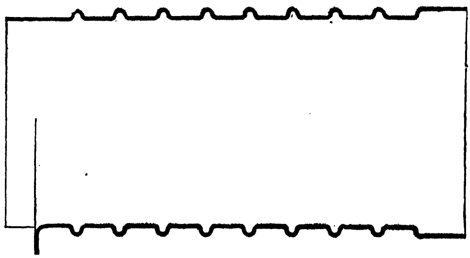


FIG. 36

flange of the head, it is swung so as to bring it central with the furnace opening. From this position it can be slid back against the tube-sheet of the combustion chamber.

39. Purves Ribbed Furnace.—A Purves ribbed furnace flue is shown in Fig. 36. The height of the ribs is $1\frac{3}{8}$ inches and the distance from center to center of ribs is 9 inches. The thickness of the flue must not be less than $\frac{7}{16}$ inch, and the length of the plain part of the ends not more than 9 inches. This form of flue is a modification of the built-up bowling-ring principle of construction.

There are other corrugated furnaces having similar construction, such as the following: the *Leeds corrugated furnace*, which has the corrugations pitched 8 inches between centers and not less than $2\frac{1}{4}$ inches deep; the *Fox corrugated furnace*, hav-

ing corrugations pitched 8 inches between centers and not less than $1\frac{1}{2}$ inches deep; and the *Brown corrugated furnace,* having corrugations 9 inches from center to center and not less than $1\frac{5}{8}$ inches deep. The plate thickness of the Leeds, Morison, Fox, and Brown furnaces should be not less than $\frac{5}{16}$ inch; for the Purves furnace and other furnaces having corrugations not over 18 inches from center to center, the plate thickness should not be less than $\frac{7}{16}$ inch.

COMBUSTION CHAMBERS

40. Purpose of Combustion Chamber.—The combustion chamber of a steam boiler is an enclosed space that provides a place for the unconsumed gases to be mixed thoroughly with air, which promotes their complete combustion. In some cases, a small quantity of air is admitted into the chamber from the ash-pit through small openings in the bridge wall or in the diaphragm below the bridge wall. In other cases, the air is admitted through small perforations in the furnace door. Sometimes, the excess of air that passes through the grates is depended on to produce the complete combustion of the gases in the combustion chamber; or, small openings may be made in the sides of the combustion chamber through which the air may enter.

41. In all cases, provision should be made to regulate the quantity of air admitted to the combustion chamber, because, to consume the gases completely, more air is required under some conditions than under others. If bituminous coals are used, a large quantity of air will be required, while with anthracite much less air will be needed. The lowest temperature at which ignition of the gases can take place is about 1,800° F. It is, therefore, evident that if the gases are cooled below the point of ignition by too much air, or by coming in contact with heating surfaces before combustion is completed, they will be carried to the smokestack unconsumed. It follows that the furnace must be of sufficient height to provide a space in which the great volume of gas can burn before being cooled, or else there must

be, adjacent to the furnace, a combustion chamber in which the gases can burn.

42. Forms of Combustion Chambers.—Internally fired boilers have built-in combustion chambers. The combustion chamber is constructed of steel plates which are riveted and

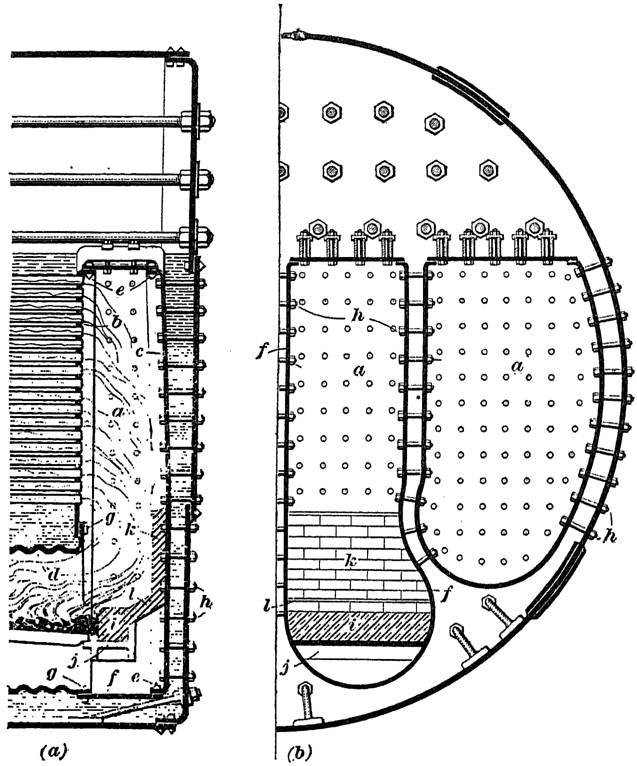


Fig. 37

stayed to withstand safely the steam pressure carried by the boiler. The design of the internal combustion chamber depends on the form of the boiler. Usually it is made circular at the bottom to conform to the curvature of the boiler shell. The upper plates are either straight or arched and are braced by suitable forms of stays.

Externally fired boilers usually have brick settings that contain the furnaces and combustion chambers. Their design depends on the type and size of boiler. Fire-tube boilers have combustion chambers of different forms from those of water-tube boilers.

43. Combustion Chambers of Scotch Boilers.—The arrangement of the combustion chambers of a Scotch boiler depends on whether the boiler is single-ended or double-ended. Fig. 37 (*a*) and (*b*) shows a longitudinal and a transverse section of a four-furnace single-ended Scotch boiler and illustrates the details of arrangement of the combustion chambers *a*. Each of the chambers communicates with the front head of the boiler through a separate corrugated furnace flue. This construction is considered preferable to that in which a single combustion chamber is common to all the furnaces, although the latter is the cheaper to construct. The front sheet of the combustion chamber, which is also the tube-sheet, is shown at *b*, and the rear sheet at *c*; *d* is the furnace flue. The tube-sheet and the rear sheet are flanged inwards, as shown at *e*, and the side sheets *f* and the crown sheet are riveted to the flanges. A circular opening is cut in the lower part of the tube-sheet to receive the rear end of the furnace flue, the two being firmly riveted togther, as shown at *g*.

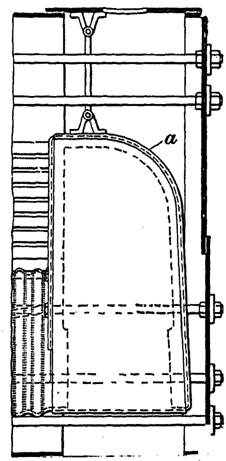


Fig. 38

44. Combustion chambers of Scotch boilers are secured to the shell and the rear head of the boiler and to each other by staybolts, as shown at *h*, Fig. 37. The bridge wall *i*, which is constructed of firebrick, is built on the cast-iron bearing bar *j*. The brickwork extends across the floor of the combustion chamber and up the rear sheet of this chamber for some distance above the top of the furnace flue, as shown at *k* and *l*, to protect the metal at those points from the intense heat of the flame, which otherwise would impinge directly against it.

Combustion chambers are sometimes constructed with round or arched backs, as shown at *a*, Fig. 38. The purpose of this is to facilitate the flow of the gases of combustion into the tubes, the curved top of the combustion chamber acting as a deflector for the gases. A sheet of this form does not require such extensive bracing as does a flat crown sheet.

PIPES AND PIPE FITTINGS

PIPES

PIPE MATERIALS

WROUGHT PIPE

1. Wrought-Iron and Mild-Steel Pipe.—Boiler-room piping is generally made of wrought iron or of mild steel, that is, soft steel. For most piping mild steel is suitable and withstands higher working pressures than genuine wrought-iron pipe, and on account of its lower cost it is generally employed. Genuine wrought-iron pipe is more durable and withstands the corrosive elements; therefore, for pipes placed in the ground, boiler blow-off connections, pipe drains and drips, etc., wrought-iron pipe is preferable. The term *wrought pipe* is applied in the trade to both wought-iron and steel pipe and it is the trade custom to supply mild-steel pipe unless genuine wrought-iron pipe is specified.

2. Commercial Grades of Wrought Pipe.—Wrought pipe, which includes both wrought iron and steel, is classified according to weight as *standard*, *extra heavy*, *double extra heavy*, and *large O. D.* The first three classes are designated by nominal diameter, which ranges from $\frac{1}{8}$ inch up. The dimensions and weight of various sizes of standard wrought pipe are given in Table I. It should be observed that the actual inside diameter, in pipes under the 1-inch size, is considerably greater than the nominal diameter. Standard pipe is usually sold in lengths

TABLE I

DIMENSIONS OF STANDARD WROUGHT PIPE

Diameter			Thickness Inch	Circumference		Transverse Areas			Length of Pipe per Square Foot of		Length of Pipe Containing One Cubic Foot Feet	Nominal Weight per Foot Pounds	Number of Threads per Inch
Nominal Internal Inches	Actual External Inches	Approximate Internal Inches		External Inches	Internal Inches	External Square Inches	Internal Square Inches	Metal Square Inches	External Surface Feet	Internal Surface Feet			
$\frac{1}{8}$	.405	.270	.068	1.272	.848	.129	.0573	.0717	9.440	14.150	2,513.000	.241	27
$\frac{1}{4}$	.540	.364	.088	1.696	1.144	.229	.1041	.1249	7.075	10.490	1,383.300	.420	18
$\frac{3}{8}$	.675	.494	.091	2.121	1.552	.358	.1917	.1663	5.657	7.730	751.200	.559	18
$\frac{1}{2}$	.840	.623	.109	2.639	1.957	.554	.3048	.2492	4.547	6.130	472.400	.837	14
$\frac{3}{4}$	1.050	.824	.113	3.299	2.589	.866	.5333	.3327	3.637	4.635	270.000	1.115	14
1	1.315	1.048	.134	4.131	3.292	1.358	.8626	.4954	2.904	3.645	166.900	1.668	$11\frac{1}{2}$
$1\frac{1}{4}$	1.660	1.380	.140	5.215	4.335	2.164	1.4960	.6680	2.301	2.768	96.250	2.244	$11\frac{1}{2}$
$1\frac{1}{2}$	1.900	1.611	.145	5.069	5.061	2.835	2.0380	.7970	2.010	2.371	70.660	2.678	$11\frac{1}{2}$
2	2.375	2.067	.154	7.401	6.494	4.430	3.3560	1.0740	1.608	1.848	42.910	3.609	$11\frac{1}{2}$
$2\frac{1}{2}$	2.875	2.468	.204	9.032	7.753	6.492	4.7840	1.7080	1.328	1.547	30.100	5.739	8
3	3.500	3.067	.217	10.996	9.636	9.621	7.3880	2.2430	1.091	1.245	19.500	7.536	8
$3\frac{1}{2}$	4.000	3.548	.226	12.566	11.146	12.566	9.8870	2.6790	.955	1.077	14.570	9.001	8
4	4.500	4.026	.237	14.137	12.648	15.904	12.7300	3.1740	.849	.949	11.310	10.665	8
$4\frac{1}{2}$	5.000	4.508	.246	15.708	14.162	19.635	15.9610	3.6740	.764	.848	9.020	12.490	8
5	5.563	5.045	.259	17.477	15.849	24.306	19.9900	4.3160	.687	.757	7.200	14.502	8
6	6.625	6.065	.280	20.813	19.054	34.472	28.8880	5.5840	.577	.630	4.980	18.762	8
7	7.625	7.023	.301	23.955	22.063	45.664	38.7380	6.9260	.501	.544	3.720	23.271	8
8	8.625	7.982	.322	27.096	25.076	58.426	50.0400	8.3860	.443	.478	2.880	28.177	8
9	9.625	8.937	.344	30.238	28.076	72.760	62.7300	10.0300	.397	.427	2.290	33.701	8
10	10.750	10.019	.366	33.772	31.477	90.763	78.8390	11.9240	.355	.382	1.820	40.065	8
11	11.750	11.000	.375	36.914	34.558	108.434	95.0330	13.4010	.325	.347	1.510	45.028	8
12	12.750	12.000	.375	40.055	37.700	127.677	113.0980	14.5790	.299	.319	1.270	48.985	8
13	14.000	13.250	.375	43.982	41.626	153.938	137.8870	16.0510	.273	.288	1.040	53.921	8
14	15.000	14.250	.375	47.124	44.768	176.715	159.4850	17.2300	.255	.268	.903	57.893	8
15	16.000	15.250	.375	50.260	48.480	210.060	187.0400	14.0200	.239	.248	.770	62.000	8

of from 18 to 20 feet. Hydrostatic tests are made at the mill to detect defects in the welds or other parts of the pipe. Each manufacturer has his own schedule of tests, but the average is somewhat like the following: Standard butt-welded wrought pipe in sizes from $\frac{1}{8}$ inch to 3 inches is tested to from 700 to 1,000 pounds per square inch; standard lap-welded pipe, in sizes from $1\frac{1}{2}$ to 12 inches, to from 500 to 1,000 pounds. The test pressures on extra-heavy and double extra-heavy wrought pipe range from 1,000 to 3,000 pounds. Cold-drawn seamless steel tubing can be obtained in standard and extra-heavy grades in sizes from $\frac{1}{8}$ inch to 4 inches in diameter.

3. Extra-heavy pipe has the same external dimensions as standard pipe, but the wall of the pipe is made heavier, which reduces the internal diameter. The internal diameter should be taken into account when pipe of this kind is required. Extra-heavy pipe is shipped without threaded ends and couplings, unless they are specified. It is used for high steam pressures, for feedwater piping, and for heavy pressures in hydraulic work. Table II gives the respective dimensions and weight of the pipe.

Double extra-heavy pipe has a thicker wall than extra-heavy pipe, but its internal diameter is less. Its external diameter is the same as that of standard wrought pipe. It is used for very high pressures and for structural purposes. Double extra-heavy pipe is always shipped without threads and couplings, unless specified in the order. Table III gives the dimensions and weight of the pipe.

Large O. D. pipes are designated by their external diameter, which ranges from 15 inches up to and including 30 inches. Large O. D. pipes have a wall thickness ranging from $\frac{1}{4}$ to $\frac{3}{4}$ inch.

4. *Cast-iron pipe*, owing to its low tensile strength, is seldom used in high-pressure work; however, it is employed in low-pressure heating systems for main steam pipes, in places where acids are employed, and where pipes are laid in the ground and left unprotected. *Cast-steel pipe* is used for superheater headers and where high temperatures exist, but owing

TABLE II

DIMENSIONS AND WEIGHT OF EXTRA-HEAVY WROUGHT PIPE

(*Crane Co.*)

Diameter			Nominal Thickness Inch	Circumference		Transverse Areas			Length of Pipe per Square Foot of		Length of Pipe Containing One Cubic Foot Feet	Nominal Weight per Foot Plain Ends Pounds
Nonimal Internal Inches	Actual External Inches	Approximate Internal Inches		External Inches	Internal Inches	External Square Inches	Internal Square Inches	Metal Square Inches	External Surface Feet	Internal Surface Feet		
1/8	.405	.215	.095	1.272	.675	.129	.036	.093	9.431	17.766	3,966.392	.314
1/4	.540	.302	.119	1.696	.949	.229	.072	.157	7.073	12.648	2,010.290	.535
3/8	.675	.423	.126	2.121	1.329	.358	.141	.217	5.658	9.030	1,024.689	.738
1/2	.840	.546	.147	2.639	1.715	.554	.234	.320	4.547	6.995	615.017	1.087
3/4	1.050	.742	.154	3.299	2.331	.866	.433	.433	3.637	5.147	333.016	1.473
1	1.315	.957	.179	4.131	3.007	1.358	.719	.639	2.904	3.991	200.193	2.171
1 1/4	1.660	1.278	.191	5.215	4.015	2.164	1.283	.881	2.301	2.988	112.256	2.996
1 1/2	1.900	1.500	.200	5.969	4.712	2.835	1.767	1.068	2.010	2.546	81.487	3.631
2	2.375	1.939	.218	7.461	6.092	4.430	2.953	1.477	1.608	1.969	48.766	5.022
2 1/2	2.875	2.323	.276	9.032	7.298	6.492	4.238	2.254	1.328	1.644	33.976	7.661
3	3.500	2.900	.300	10.996	9.111	9.621	6.605	3.016	1.091	1.317	21.801	10.252
3 1/2	4.000	3.364	.318	12.566	10.568	12.566	8.888	3.678	.954	1.135	16.202	12.505
4	4.500	3.826	.337	14.137	12.020	15.904	11.497	4.407	.848	.998	12.525	14.983
4 1/2	5.000	4.290	.355	15.708	13.477	19.635	14.455	5.180	.763	.890	9.962	17.611
5	5.563	4.813	.375	17.477	15.120	24.306	18.194	6.112	.686	.793	7.915	20.778
6	6.625	5.761	.432	20.813	18.099	34.472	26.067	8.405	.576	.663	5.524	28.573
7	7.625	6.625	.500	23.955	20.813	45.664	34.472	11.192	.500	.576	4.177	38.048
8	8.625	7.625	.500	27.096	23.955	58.426	45.663	12.763	.442	.500	3.154	43.388
9	9.625	8.625	.500	30.238	27.096	72.760	58.426	14.334	.396	.442	2.464	48.728
10	10.750	9.750	.500	33.772	30.631	90.763	74.662	16.101	.355	.391	1.929	54.735
11	11.750	10.750	.500	36.914	33.772	108.434	90.763	17.671	.325	.355	1.587	60.075
12	12.750	11.750	.500	40.055	36.914	127.676	108.434	19.242	.299	.325	1.328	65.415

TABLE III

DIMENSIONS AND WEIGHT OF DOUBLE EXTRA-HEAVY WROUGHT PIPE

Diameter			Nominal Thickness	Circumference		Transverse Areas			Length of Pipe per Square Foot of		Length of Pipe Containing One Cubic Foot	Nominal Weight per Foot Plain Ends
Nominal Internal Inches	Actual External Inches	Approximate Internal Inches	Inch	External Inches	Internal Inches	External Square Inches	Internal Square Inches	Metal Square Inches	External Surface Feet	Internal Surface Feet	Feet	Pounds
½	.840	.252	.294	2.639	.792	.554	.050	.504	4.547	15.157	2,887.164	1.714
¾	1.050	.434	.308	3.299	1.363	.866	.148	.718	3.637	8.801	973.404	2.440
1	1.315	.599	.358	4.131	1.882	1.358	.282	1.076	2.904	6.376	510.998	3.659
1¼	1.660	.896	.382	5.215	2.815	2.164	.630	1.534	2.301	4.263	228.379	5.214
1½	1.900	1.100	.400	5.969	3.456	2.835	.950	1.885	2.010	3.472	151.526	6.408
2	2.375	1.503	.436	7.461	4.722	4.430	1.774	2.656	1.608	2.541	81.162	9.029
2½	2.875	1.771	.552	9.031	5.564	6.492	2.464	4.028	1.328	2.156	58.457	13.695
3	3.500	2.300	.600	10.996	7.226	9.621	4.155	5.466	1.091	1.660	34.659	18.583
3½	4.000	2.728	.636	12.566	8.570	12.566	5.845	6.721	.954	1.400	24.637	22.850
4	4.500	3.152	.674	14.137	9.902	15.904	7.803	8.101	.848	1.211	18.454	27.541
4½	5.000	3.580	.710	15.708	11.247	19.635	10.066	9.569	.763	1.066	14.306	32.530
5	5.563	4.063	.750	17.477	12.764	24.306	12.966	11.340	.686	.940	11.107	38.552
6	6.625	4.897	.864	20.813	15.384	34.472	18.835	15.637	.576	.780	7.646	53.160
7	7.625	5.875	.875	23.955	18.457	45.664	27.109	18.555	.500	.650	5.312	63.079
8	8.625	6.875	.875	27.096	21.598	58.426	37.122	21.304	.442	.555	3.879	72.424

to its high cost and difficulty of manufacture without blowholes and other hidden defects, it is not extensively employed for piping purposes. *Brass* and *copper pipes* are more expensive than mild-steel and wrought-iron pipe, but they with-

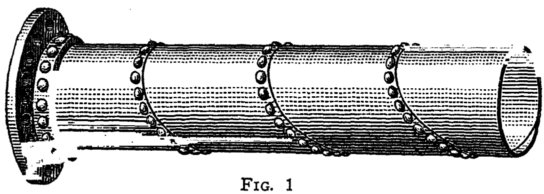
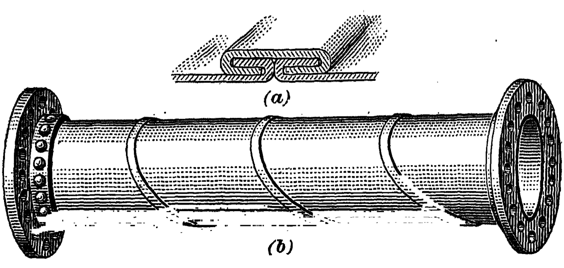


FIG. 1

stand the corrosive action of hot water better than wrought-iron and steel pipe. Owing to their high cost, low tensile strength, and weakness at high temperatures, these materials are not used for piping in high-pressure work to any great extent. They are used for pipe coils in water tanks and in steam tanks or condensers and for boiler connections where there is great liability of corrosion, such as between feed-pumps and boilers. When brass feedwater piping is used, the diameter need not be so large as when extra-heavy steel pipe is used, because there will be no scaling or corrosion to obstruct the flow of water.

5. Galvanized Pipe.—The galvanized pipe used in the smaller sizes is regular wrought-iron or steel pipe coated inside



(a)

(b)

FIG. 2

and outside with zinc. It has the same dimensions as are given in Table I. Galvanized pipe is used for water mains, for underground piping, and where corrosion may occur, as its coating of zinc prevents rapid oxidization or rusting of the

metal. Sometimes it is desirable to know whether a galvanized pipe is made of wrought iron or steel. This may be determined by subjecting a piece of the pipe to the hammer test. On

TABLE IV

STANDARD SPIRAL-JOINTED PRESSURE PIPE, DOUBLE GALVANIZED

Inside Diameter Inches	Dimensions and Weight			
	Approximate Weight per Foot Pounds	Thickness B. W. Gauge Number	Diameter of Flanges Inches	Approximate Bursting Pressure Pounds
3	$2\frac{1}{4}$	20	6	1,500
4	3	20	7	1,125
5	4	20	8	900
6	5	18	9	1,000
7	6	18	10	860
8	7	18	11	750
9	8	18	13	665
10	11	16	14	750
11	12	16	15	680
12	14	16	16	625
13	15	16	17	575
14	20	14	18	670
15	22	14	19	625
16	24	14	$21\frac{1}{4}$	585
18	29	14	$23\frac{1}{4}$	520
20	34	14	$25\frac{1}{8}$	470
22	40	12	$28\frac{1}{4}$	595
24	50	12	30	540
26	58	12	$34\frac{1}{4}$	505
28	72	10	$36\frac{1}{2}$	605
30	79	10	$38\frac{3}{4}$	560
32	85	10	41	525
36	94	10	$45\frac{3}{4}$	469
40	106	10	50	420

hammering the test piece, if the coating of zinc flakes and falls off, the pipe is steel, whereas, if the pipe is of wrought iron, the zinc coating adheres to the surface and shows little effect of the blows. By continuing the test until the pipe is flattened

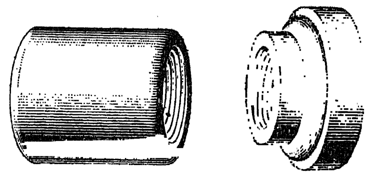
out, the fracture of the metal will show, in the case of wrought-iron pipe, a ragged and fibrous structure, having a dull gray color. In the case of steel the fracture will appear even in texture, having a bright and crystalline appearance; but it develops a dull appearance when exposed to the atmosphere. It will be noted, in threading wrought-iron pipe, that the chips are fibrous and easily break or crumble; but with steel the chip is smooth, tending to curl up and form spirals that are hard and wiry.

6. Spiral Jointed Pipe.—In the manufacture of spiral pipe, strips of steel plate are rolled into a cylindrical pipe as shown in Figs. 1 and 2. The seam may be riveted, as in Fig. 1, or lap-welded; or, a lock seam like that shown in section in Fig. 2 (*a*) may be used. The latter is rolled into a continuous interlocking seam as shown in (*b*). The ends of the pipe are fitted at the factory with cast-iron or steel flanges, which are either welded or riveted to the pipe. Bolt holes are drilled in the flanges so that the pipe sections can be bolted together. The pipes are covered inside and outside with either a zinc coating or an asphaltum paint to protect them from corrosion. They range from 3 to 40 inches in diameter and are cut in lengths up to and including 20 feet. The spiral arrangement of the seam produces a stiff and very strong structure, so that thinner metal can be used than is possible with ordinary riveted or welded pipe. The safe working pressure of spiral pipe is considered to be one-third of the bursting pressure. Spiral pipe is suitable for exhaust steam pipes, water piping, smokestacks, and compressed-air piping. Table IV gives data on the plate thickness and weight of pipe per foot of length, size of flanges, and bursting pressure for spiral pipe.

PIPE FITTINGS

7. Materials for Fittings.—The materials used in the manufacture of pipe fittings are cast iron, cast steel, malleable iron, wrought iron, and brass. Cast iron is used for pipe connections and boiler fittings on pipes for saturated steam, for boiler feedwater piping, and for low-pressure heating work.

Cast steel and wrought-iron fittings are employed on high-pressure piping and on pipes for superheated steam, as well as on high-pressure feed lines and blow-off connections. Brass flanges and piping are used very little, and then only in the form of screwed connections.



(a) (b)

Fig. 3

8. Pipe Couplings.—Pipe couplings are short sleeves threaded on the inside and are used to connect lengths of pipe. They may be obtained for standard, extra-heavy, and double extra-heavy piping. A common form of wrought coupling is shown in Fig. 3 (*a*). It is threaded at each end with a right-hand pipe thread. Standard pipe is furnished in lengths threaded at one end and fitted with couplings at the other end. If two pipes of different diameters are to be connected, a *reducing coupling*, as shown in (*b*), may be used. Its ends are threaded to receive the two sizes of pipe.

9. Pipe Unions.—Pipe unions are used for making the final connections in lines or systems of piping. They are of two classes, namely, *nut unions* and *flange unions*, the latter being commonly called pipe flanges. One type of nut union is shown in Fig. 4. The part *a*, made of brass, is screwed on the end of one pipe, and the part *c*, carrying the nut *b* loose on it, is screwed on the end of the adjoining section. The ends of the parts *a* and *c* are then brought together and the nut *b* is screwed on to the part *a*, making a tight metal-to-metal joint at *d*. The faces at the joint *d* may be ground spherical or may be beveled. No gasket is required to produce a water-tight or steam-tight joint. Nut unions are made for pipes from $\frac{1}{8}$ inch to 4 inches in diameter. For medium pressures, unions are used on pipes up to 2 inches in diameter, and flange unions for larger sizes of pipe.

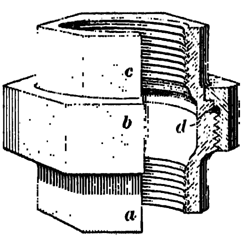


Fig. 4

10. The pipe union shown in Fig. 5 represents a type that is used in high-pressure steam and hydraulic work for pipes up to 3 inches in diameter. It is made of forged steel throughout and has a **V**-shaped ground joint, as shown at *a*. When the parts *b* and *c* are drawn together by the union ring *d*, the projecting **V** enters the groove in the part *b*, forming a steam-tight metal-to-metal joint along the surfaces *a* and *e*. The slot *f* in the **V**-shaped tongue is to take care of the slight changes due to expansion and contraction caused by variations of temperature in high-pressure work.

11. Flange Unions.—Lengths of pipe may be joined in a continuous line by the use of flange unions such as are shown in Fig. 6. The flanges *a* and *b* are circular metal rings threaded

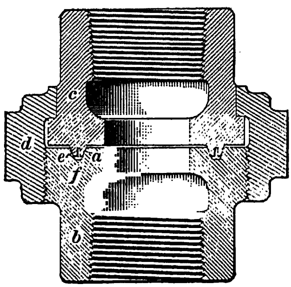


FIG. 5

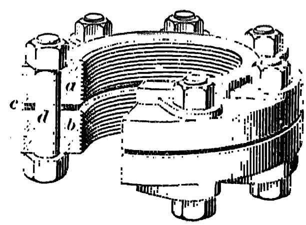


FIG. 6

on the inside so that they may be screwed on the ends of the pipes that are to be joined. The flanges are then brought together, face to face, a gasket *c* is placed between them, the bolts *d* are inserted in holes drilled through the flanges, and the nuts are drawn up. The faces of the flanges are machined and the pipe sections are lined up so that the faces of the flanges are parallel. Compression of the gasket between the flat faces then produces a water-tight or steam-tight joint. Flange unions are made of brass in standard sizes from $\frac{1}{2}$ inch to 6 inches for steam pressures up to 125 pounds per square inch, and extra-heavy flanges are made for pressures up to 250 pounds per square inch. Cast-iron and malleable-iron flange unions may be obtained for pressures up to 250 pounds and for pipe sizes from $\frac{1}{2}$ inch upwards. For very high

pressures, flange unions are made of steel. All types of flange unions are sold in pairs.

12. Pipe Flanges.—For joining pipes that are to be subjected to medium and high working pressures, pipe flanges of the type usually called *companion flanges* are extensively used. The cost of these flanges is greater than that of unions

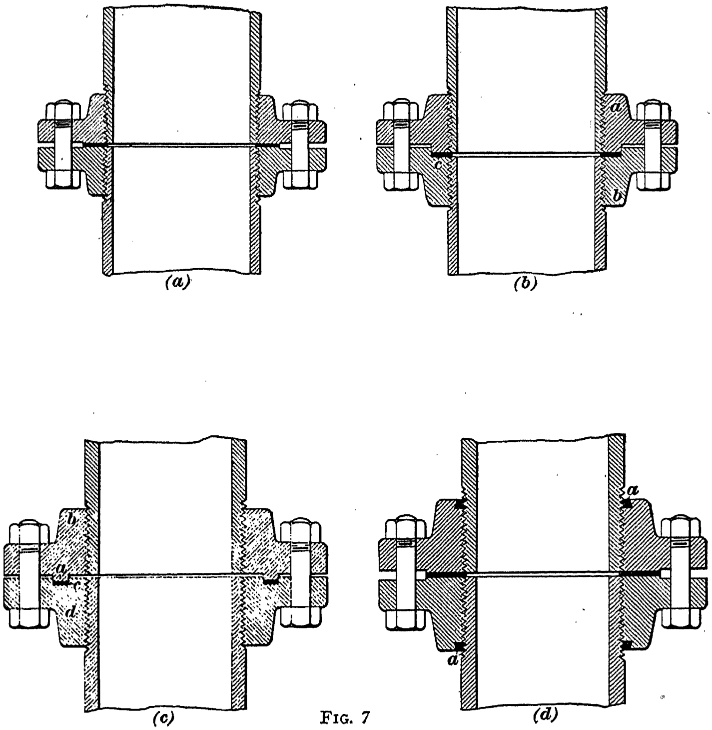


Fig. 7

for the same work, and some styles of flanges require special machinery for attaching them to the sections of pipe. However, the additional cost is warranted by their freedom from leaks, their reliability, and the advantages they possess in case alterations and repairs must be made on lines on which they are used.

A majority of the manufacturers of flanged fittings and valves have agreed on standard dimensions for the thickness

and diameter of the flanges, the diameter of bolts and holes, the number and size of bolts, and the diameter of the bolt circles; unless specially ordered otherwise, flanges are generally made according to this standard. This standard was recommended for adoption by a joint committee of the American Society of Mechanical Engineers and the Master Steam Fitters' Association; it is known as the Manufacturers' Standard.

13. Types of Pipe Flanges.—Several types of companion flanges are shown in Fig. 7. The screwed flange in (*a*) is the least expensive style, and is satisfactory for low and medium pressures. The flange is screwed on until the end of the pipe projects through it. Then the end is cut off flush with the face and both are faced so that the surface is square with the center line of the pipe. Sometimes the face of the flange has a number of shallow concentric grooves cut in it, allowing a soft gasket to be used between adjacent flanges without danger of its being blown out. In (*b*) are shown male and female flanges. The male flange *a* has a shoulder that fits into a corresponding recess in the female flange *b*, a gasket *c* being inserted in the recess to make a tight joint. A tongue-and-groove type is shown in (*c*), the tongue *a* on the flange *b* fitting into the groove *c* in the flange *d*, in the bottom of which a gasket is placed. The flanges in (*d*) have raised faces, between which the gasket is held, and recesses are provided at *a* to enable the pipe joints to be calked.

The disadvantages of the types shown in (*b*) and (*c*) are that great care must be taken in manufacture to insure alinement of faces, tongues, and grooves, to prevent subsequent trouble through leaky joints; and if a break occurs in the gasket, the ends of the pipe must be sprung apart to allow a new gasket to be inserted.

Table V shows the dimensions of standard flanges and flange bolts and Table VI gives similar data for extra-heavy flanges. Flanges are designed with an unusually large factor of safety, to cover possible defects in the metal or imperfections in casting. In all cases, it is important that the castings shall be absolutely sound and free from flaws, blowholes, and shrinkage cracks.

14. Gaskets for Flanges.—Packing rings, or gaskets, for steam-pipe flanges and flange unions may be made of various materials. In low-pressure heating systems, composition

TABLE V

DIMENSIONS OF STANDARD THREADED PIPE FLANGES

(For Pressures up to 125 Pounds per Square Inch—Manufacturers' Standard)

Pipe Size Inches	Pipe Flanges			Bolts		
	Outside Diameter Inches	Thickness of Flange Inches	Diameter of Bolt Circle Inches	Number of Bolts Required	Diameter of Bolt Inches	Length of Bolt Inches
1	4	$\frac{7}{16}$	3	4	$\frac{7}{16}$	$1\frac{1}{2}$
$1\frac{1}{4}$	$4\frac{1}{2}$	$\frac{1}{2}$	$3\frac{3}{8}$	4	$\frac{7}{16}$	$1\frac{1}{2}$
$1\frac{1}{2}$	5	$\frac{9}{16}$	$3\frac{7}{8}$	4	$\frac{1}{2}$	$1\frac{3}{4}$
2	6	$\frac{5}{8}$	$4\frac{3}{4}$	4	$\frac{5}{8}$	2
$2\frac{1}{2}$	7	$\frac{11}{16}$	$5\frac{1}{2}$	4	$\frac{5}{8}$	$2\frac{1}{4}$
3	$7\frac{1}{2}$	$\frac{3}{4}$	6	4	$\frac{5}{8}$	$2\frac{1}{4}$
$3\frac{1}{2}$	$8\frac{1}{2}$	$\frac{13}{16}$	7	4	$\frac{5}{8}$	$2\frac{1}{2}$
4	9	$\frac{15}{16}$	$7\frac{1}{2}$	8	$\frac{5}{8}$	$2\frac{3}{4}$
$4\frac{1}{2}$	$9\frac{1}{4}$	$\frac{15}{16}$	$7\frac{3}{4}$	8	$\frac{3}{4}$	$2\frac{3}{4}$
5	10	$\frac{15}{16}$	$8\frac{1}{2}$	8	$\frac{3}{4}$	$2\frac{3}{4}$
6	11	1	$9\frac{1}{2}$	8	$\frac{3}{4}$	3
7	$12\frac{1}{2}$	$1\frac{1}{16}$	$10\frac{3}{4}$	8	$\frac{3}{4}$	3
8	$13\frac{1}{2}$	$1\frac{1}{8}$	$11\frac{3}{4}$	8	$\frac{3}{4}$	$3\frac{1}{4}$
9	15	$1\frac{1}{8}$	$13\frac{1}{4}$	12	$\frac{3}{4}$	$3\frac{1}{4}$
10	16	$1\frac{3}{16}$	$14\frac{1}{4}$	12	$\frac{7}{8}$	$3\frac{1}{2}$
12	19	$1\frac{1}{4}$	17	12	$\frac{7}{8}$	$3\frac{1}{2}$
14	21	$1\frac{3}{8}$	$18\frac{3}{4}$	12	1	4
15	$22\frac{1}{4}$	$1\frac{3}{8}$	20	16	1	4
16	$23\frac{1}{2}$	$1\frac{7}{16}$	$21\frac{1}{4}$	16	1	4
18	25	$1\frac{9}{16}$	$22\frac{3}{4}$	16	$1\frac{1}{8}$	$4\frac{1}{2}$
20	$27\frac{1}{2}$	$1\frac{11}{16}$	25	20	$1\frac{1}{8}$	$4\frac{3}{4}$
22	$29\frac{1}{2}$	$1\frac{13}{16}$	$27\frac{1}{4}$	20	$1\frac{1}{4}$	5
24	32	$1\frac{7}{8}$	$29\frac{1}{2}$	20	$1\frac{1}{4}$	$5\frac{1}{4}$

NOTE.—Flanges, flange fittings, valves, etc. have the bolt holes drilled in multiples of four, so that fittings may be made to face in any quarter and holes straddle the center line. All bolt holes are drilled $\frac{1}{8}$ inch larger than the diameter of bolts.

packing rings of asbestos, rubber, etc., are used. For high-pressure steam lines, a corrugated copper gasket like that shown at *a*, Fig. 8, is reliable, as it can be drawn up tight without danger of compressing the material into the pipe and it

will effectively resist a very high temperature. For hydraulic pipe flanges, reinforced rubber packing and composition packing to resist very high water pressures are used.

TABLE VI

DIMENSIONS OF EXTRA-HEAVY THREADED PIPE FLANGES

(For Pressures up to 250 Pounds per Square Inch—Manufacturers' Standard)

Pipe Size Inches	Pipe Flanges			Bolts			
	Outside Diameter Inches	Thickness of Flange Inches	Depth of Thread Inches	Number Required	Diameter Inches	Length Inches	Diameter of Bolt Circle Inches
1	$4\frac{1}{2}$	$\frac{11}{16}$	1	4	$\frac{1}{2}$	2	$3\frac{1}{4}$
$1\frac{1}{4}$	5	$\frac{3}{4}$	$1\frac{1}{8}$	4	$\frac{1}{2}$	$2\frac{1}{4}$	$3\frac{3}{4}$
$1\frac{1}{2}$	6	$\frac{13}{16}$	$1\frac{1}{4}$	4	$\frac{5}{8}$	$2\frac{1}{2}$	$4\frac{1}{2}$
2	$6\frac{1}{2}$	$\frac{7}{8}$	$1\frac{3}{8}$	4	$\frac{5}{8}$	$2\frac{1}{2}$	5
$2\frac{1}{2}$	$7\frac{1}{2}$	1	$1\frac{7}{16}$	4	$\frac{3}{4}$	3	$5\frac{7}{8}$
3	$8\frac{1}{4}$	$1\frac{1}{8}$	$1\frac{9}{16}$	8	$\frac{3}{4}$	$3\frac{1}{4}$	$6\frac{5}{8}$
$3\frac{1}{2}$	9	$1\frac{3}{16}$	$1\frac{5}{8}$	8	$\frac{3}{4}$	$3\frac{1}{4}$	$7\frac{1}{4}$
4	10	$1\frac{1}{4}$	$1\frac{3}{4}$	8	$\frac{3}{4}$	$3\frac{1}{2}$	$7\frac{7}{8}$
$4\frac{1}{2}$	$10\frac{1}{2}$	$1\frac{5}{16}$	$1\frac{13}{16}$	8	$\frac{3}{4}$	$3\frac{1}{2}$	$8\frac{1}{2}$
5	11	$1\frac{3}{8}$	$1\frac{7}{8}$	8	$\frac{3}{4}$	$3\frac{3}{4}$	$9\frac{1}{4}$
6	$12\frac{1}{2}$	$1\frac{7}{16}$	2	12	$\frac{3}{4}$	$3\frac{3}{4}$	$10\frac{5}{8}$
7	14	$1\frac{1}{2}$	$2\frac{1}{16}$	12	$\frac{7}{8}$	4	$11\frac{7}{8}$
8	15	$1\frac{5}{8}$	$2\frac{3}{16}$	12	$\frac{7}{8}$	$4\frac{1}{4}$	13
9	$16\frac{1}{4}$	$1\frac{3}{4}$	$2\frac{1}{4}$	12	1	$4\frac{3}{4}$	14
10	$17\frac{1}{2}$	$1\frac{7}{8}$	$2\frac{3}{8}$	16	1	5	$15\frac{1}{4}$
12	$20\frac{1}{2}$	2	$2\frac{9}{16}$	16	$1\frac{1}{8}$	$5\frac{1}{4}$	$17\frac{3}{4}$
14	23	$2\frac{1}{8}$	$2\frac{11}{16}$	20	$1\frac{1}{8}$	$5\frac{1}{2}$	$20\frac{1}{4}$
15	$24\frac{1}{2}$	$2\frac{3}{16}$	$2\frac{13}{16}$	20	$1\frac{1}{4}$	$5\frac{3}{4}$	$21\frac{1}{2}$
16	$25\frac{1}{2}$	$2\frac{1}{4}$	$2\frac{7}{8}$	20	$1\frac{1}{4}$	6	$22\frac{1}{2}$
18	28	$2\frac{3}{8}$	$3\frac{1}{16}$	24	$1\frac{1}{4}$	$6\frac{1}{4}$	$24\frac{3}{4}$
20	$30\frac{1}{2}$	$2\frac{1}{2}$	$3\frac{1}{4}$	24	$1\frac{3}{8}$	$6\frac{1}{2}$	27
22	33	$2\frac{5}{8}$	$3\frac{7}{16}$	24	$1\frac{1}{2}$	7	$29\frac{1}{4}$
24	36	$2\frac{3}{4}$	$3\frac{5}{8}$	24	$1\frac{5}{8}$	$7\frac{1}{2}$	32

NOTE.—Flanges, flanged fittings, valves, etc. have the bolt holes drilled in multiples of four, so that fittings may be made to face in any quarter and holes straddle the center line.

15. Types of Pipe Joints.—The joints in pipe lines subjected to low pressures may be made with unions like those shown in Figs. 4 to 6; and the screwed flange joint shown in Fig. 7 (*a*) is suitable for pipes carrying saturated steam at or

below 125 pounds pressure, for boiler-feed lines carrying not more than 150 pounds pressure, for boiler blow-off piping, and

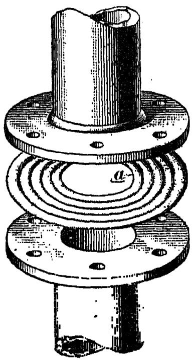


FIG. 8

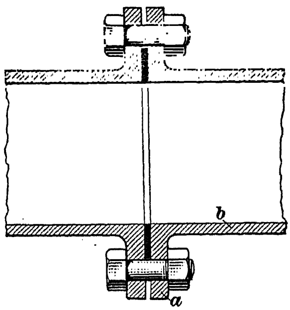


FIG. 9

for low-pressure heating systems. In joints of the foregoing types, however, the threading of the pipe reduces its strength in the joint, and so other types of joints are used for piping that is to be subjected to high working pressures.

The welded joint shown in Fig. 9 is used on high-pressure work and on pipe lines conveying superheated steam. The flange *a* is welded directly to the pipe *b*, so that the two form one piece, the welding being done usually by the electric arc. The strength of the weld depends on the care with which it is made, but the welded flange has been found stronger than the screwed flange. After the weld is completed, the face of the flange is machined, so as to make it flat and square with the center line of the pipe. A gasket is inserted between adjacent flanges.

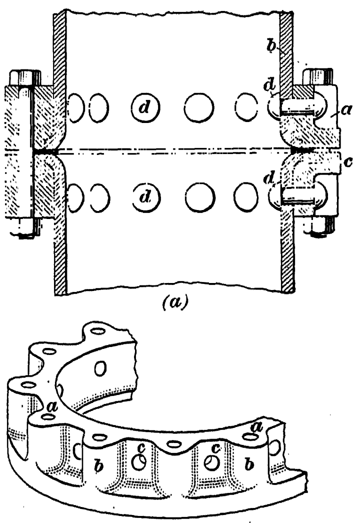


FIG. 10

16. The type of flange shown in Fig. 10 is excellent for high-pressure piping. As indicated in the sectional view (*a*), the flange *a* is shrunk on the end of the pipe *b*. In doing this, the flange is heated so as to cause it to expand, and while hot it is driven over the end of the pipe. When it cools, it shrinks and grips the pipe firmly. The inner edge *c* of the flange is rounded off and the end of the pipe is then peened over by striking it lightly with a hammer, thus giving the flange additional grip on the pipe. Sometimes the security of the fastening is further increased by riveting the pipe to the flange in the manner indicated at *d*. A part of a flange is shown in perspective in (*b*). The bolt holes *a* are formed in bosses *b*, and the spaces between the bosses enable the rivet holes *c* to be drilled and the rivets inserted and headed.

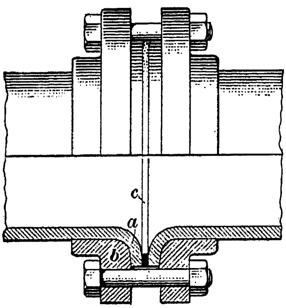


FIG. 11

17. The *Van Stone joint*, shown in Fig. 11, is made by upsetting and flanging the heated end of the pipe *a* over the flange *b*. The face of the flange of the pipe is faced smooth and to a uniform thickness, so as to produce a tight joint and perfect alinement. The edges of the flange are also finished. The flanges *b* are loose on the pipes, being a trifle larger in diameter than the outside diameter of the pipes, and serve as rings that bear on the flanges of the pipes. A gasket *c* is inserted before the flanges are bolted together. When this joint is properly made, it is strong and has no superior for durability. For high pressures, on steam and water lines, forged steel flanges should be employed. Table VII gives the principal dimensions of Van Stone flange connections.

18. A special type of flanged connection is shown in Fig. 12. The flange *a* has a shallow groove *b* on the inner surface, into which the pipe *c* is expanded by rolling under pressure. A recess is cut in the face of the flange *a*, and the end of the pipe is turned out and forced down into this recess, as at *d*, after

which it is machined, so that the face of the pipe is flush with the face of the flange *a*. A copper gasket *e* is inserted

TABLE VII

DIMENSIONS OF VAN STONE JOINTS

Pipe Size Inches	Diameter of Flange Inches	Flange Thickness Inches	Diameter of Bolt Circle Inches	Diameter of Bolt Inches	Number of Bolts Required	Length of Bolts Inches
4	10	$1\frac{1}{4}$	$7\frac{7}{8}$	$\frac{3}{4}$	8	$3\frac{3}{4}$
$4\frac{1}{2}$	$10\frac{1}{2}$	$1\frac{5}{16}$	$8\frac{1}{2}$	$\frac{3}{4}$	8	4
5	11	$1\frac{3}{8}$	$9\frac{1}{4}$	$\frac{3}{4}$	8	4
6	$12\frac{1}{2}$	$1\frac{7}{16}$	$10\frac{5}{8}$	$\frac{3}{4}$	12	$4\frac{1}{4}$
7	14	$1\frac{1}{2}$	$11\frac{7}{8}$	$\frac{7}{8}$	12	$4\frac{1}{2}$
8	15	$1\frac{5}{8}$	13	$\frac{7}{8}$	12	$4\frac{3}{4}$
9	$16\frac{1}{4}$	$1\frac{3}{4}$	14	1	12	$5\frac{1}{4}$
10	$17\frac{1}{2}$	$1\frac{7}{8}$	$15\frac{1}{4}$	1	16	$5\frac{1}{2}$
12	$20\frac{1}{2}$	2	$17\frac{3}{4}$	$1\frac{1}{8}$	16	$5\frac{3}{4}$
14	23	$2\frac{1}{8}$	$20\frac{1}{4}$	$1\frac{1}{8}$	20	6
15	$24\frac{1}{2}$	$2\frac{3}{16}$	$21\frac{1}{2}$	$1\frac{1}{4}$	20	$6\frac{1}{4}$
16	$25\frac{1}{2}$	$2\frac{1}{4}$	$22\frac{1}{2}$	$1\frac{1}{4}$	20	$6\frac{1}{2}$

and the bolts are drawn up. This form of construction has been found satisfactory for high-pressure lines carrying either steam or water, and for superheated steam as well. Tests have shown that it will withstand pressures as high as 1,250 pounds per square inch.

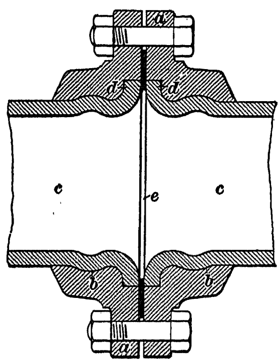


FIG. 12

19. Expansion and Contraction of Pipes.—Piping is put up at ordinary temperatures; but when steam is turned on, the temperature of the piping is increased considerably, particularly if superheated steam is being used. Increases or decreases of temperature may occur while the piping is in service. As a change of temperature causes metal to expand or contract, a line of steam piping must be so installed that expansion and contraction will not set up stresses that may

bend or break the pipe or its fittings. The linear expansion or contraction of a line of piping may be found by the formula

$$m = C\,l\,t$$

in which m = amount of linear expansion or contraction, in inches;

C = coefficient of linear expansion;

l = length of piping, in inches, before the change of temperature occurs;

t = change of temperature, in degrees Fahrenheit.

The value of C for wrought-iron or steel pipe is .00000599; for cast-iron pipe it is .00000617; and for cast-steel pipe it is .00000636.

EXAMPLE.—A steel pipe line 250 feet long is put up at a temperature of 60° F. When it is finished, superheated steam at a maximum temperature of 370° F. is turned on. Find the linear expansion.

SOLUTION.—Apply the formula just given. The pipe is of steel and so $C = .00000599$; $l = 250 \times 12 = 3{,}000$ in.; and $t = 370 - 60 = 310°$. Substitute these values, and $m = .00000599 \times 3{,}000 \times 310 = 5.57$ in., or $5\frac{9}{16}$ in., nearly. Ans.

20. Expansion Joints.—The example of the preceding article shows that the change of length of a straight pipe

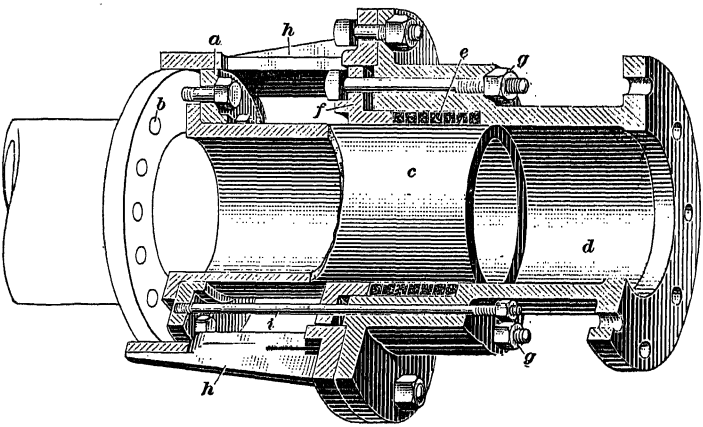


FIG. 13

line, under change of temperature, may amount to several inches. One way of preventing damage to the pipe and fittings

is to use an expansion joint, or slip joint. One type of expansion joint, shown in Fig. 13, is a slip joint that is inserted at some convenient point in the line. The flange *a* is bolted to the flange *b* of the main piping, and between them is held the flange of a short sleeve *c*. This sleeve fits inside the pipe *d*, which in turn is bolted to an adjoining section of the main steam pipe. A stuffingbox *e* is formed around the sleeve, the packing being held in place by the gland *f*, which can be drawn up by tightening the nuts *g*. Guides *h* are firmly bolted to the large flange of the section *d*, and the outer ends of these guides fit against the flanges *a* and *b*. If expansion occurs in the main piping, the sleeve *c* slips farther into the section *d*, the stuffingbox *e* preventing leakage of steam. If the piping cools and contracts, the sleeve *c* moves out of the section *d* an amount equal to the change of length. The sleeve *c* is held firmly to the flange *b* of the main pipe and moves with it. The long studs *i* prevent the joint from pulling apart completely, and are used simply as a safety device.

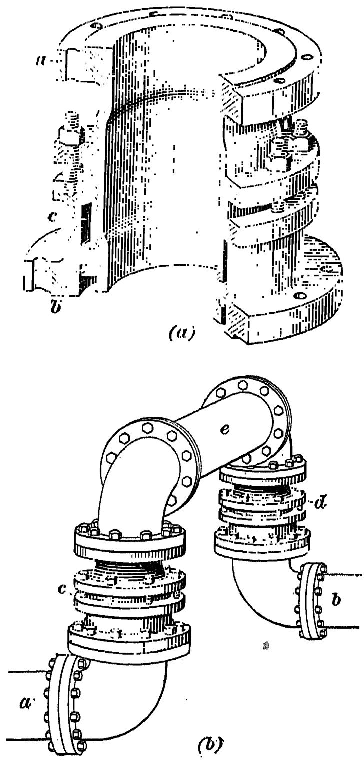


FIG. 14

21. The expansion joint shown in Fig. 13 is intended to be inserted directly in a straight run of piping, the sleeve *c* moving lengthwise to accommodate the change of length. The type shown in Fig. 14 (*a*) is a swivel expansion joint, the section *a* being held in such a way that it can turn, or swivel, inside the

section *b*. A stuffingbox *c* maintains a steam-tight joint between the two. The method of installing this joint is shown in (*b*). The sections *a* and *b* of the main steam piping are not in a straight line, but are offset. They are connected by elbows to the swivel expansion joints *c* and *d*, these being joined by the pipe *e* and connecting elbows. Thus, any change of length of the pipes *a* and *b* simply causes swiveling of the expansion joints and prevents stresses from being set up in the piping.

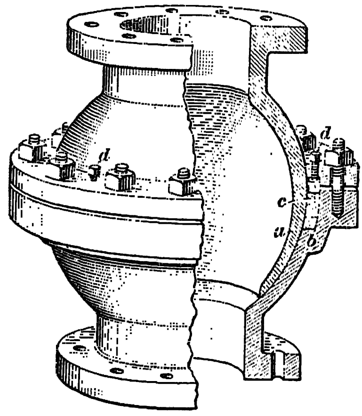


FIG. 15

A flexible joint is shown in Fig. 15. The section *a* and the section *b* into which it fits are made spherical, and a stuffingbox is provided to form a tight joint between them. The packing *c* is compressed by turning the setscrews *d*. The section *a* can move in any direction sidewise. This type of joint is made in standard and extra-heavy styles to carry pressures up to 250 pounds per square inch.

22. Damage through change of length of straight piping may be provided against by inserting a section of corrugated piping, such a section being called a corrugated expansion joint. A joint of this kind is illustrated in Fig. 16, the material of which it is made usually being copper. The elasticity of the section, due to the corrugations, allows it to be compressed or drawn out to some extent, and so it takes up expansion or contraction of the pipe line in which it is inserted. The corrugations are rolled into the sheet from which the pipe is made. The form shown is used principally

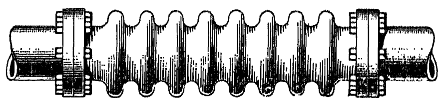


FIG. 16

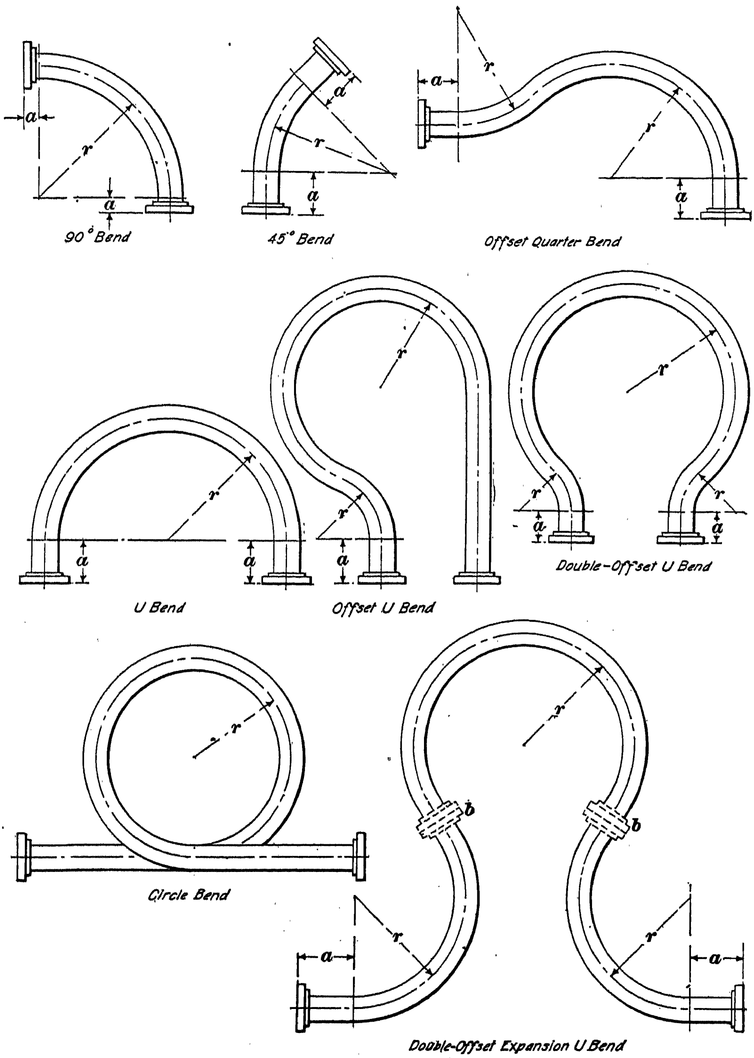
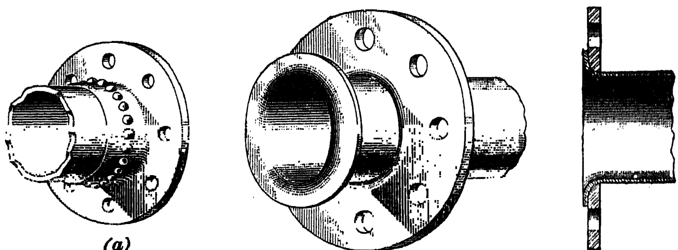

90° Bend
45° Bend
Offset Quarter Bend
U Bend
Offset U Bend
Double-Offset U Bend
Circle Bend
Double-Offset Expansion U Bend
a
r
b

FIG. 17

on exhaust-steam lines. Another form, in which iron or steel rings are used to reinforce the corrugated section and yet not interfere with its axial lengthening and shortening, is used in high-pressure work.

23. Pipe Bends.—An excellent way of allowing for expansion and contraction of pipe lines is to use pipe bends, as shown in Fig. 17. The forms of bends illustrated are used extensively on long pipe lines as well as on steam-engine connections and other piping subjected to considerable vibration. Wrought-pipe bends are made while the material is red hot. The radius *r* of the bend must be large, so as to give the proper spring to the bend and to reduce as much as possible the friction of the steam in flowing through it.



(a) (b)

FIG. 18

The larger the radius, the more fully these objects are attained. Generally, the radius should not be less than six times the diameter of the pipe. The bends are connected to other pipes by extra-heavy flanges of cast steel, forged steel, or malleable iron, these being fastened to the bends by one or other of the methods previously illustrated. A short section *a* of each bend, near the flange, is left straight, so that the flange will stand square with the axis of the adjoining section of pipe. In large bends, as, for example, the double-offset expansion **U** bend, the fitting is made in three sections, flanges being used at *b* to connect them.

Pipe bends made of copper pipe may have shorter radii, as copper is more ductile than steel and yields more readily to the bending operation without undue buckling. Small sizes

of bends are made from seamless drawn tubing, which comes in standard lengths of 12 feet. Copper bends may be fitted with either composition or brass flanges, riveted and brazed on, as shown in Fig. 18 (*a*); or they may have loose steel flanges, the ends of the pipe being flanged as shown in (*b*).

24. Pipe Coverings.—To reduce the loss of heat by radiation and convection, steam pipes are covered with *lagging*

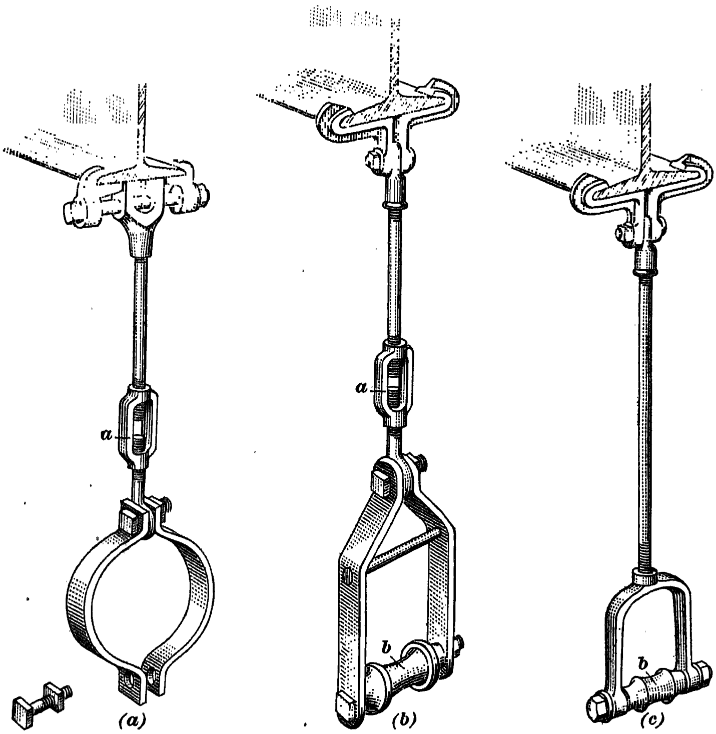


FIG. 19

made of some material that is a poor conductor of heat, such as magnesia, asbestos, slag wool, or kieselguhr, the last being a natural earth containing minute fossil shells. Sometimes, the covering material is made in the form of a cement, mixed with lime, animal hair, or vegetable fiber, and applied in a plastic form. As a rule, however, it is manufactured in short molded

sections of different sizes to fit pipes of different diameters. The sections are split lengthwise, so that they may be placed over the pipe, and are held together by a canvas jacket that may be painted or tarred to resist the weather. Polished and lacquered brass bands are also used to hold the sections in place on the pipe. Charcoal, slacked lime, and sawdust are inexpensive materials that may be placed around pipes laid in trenches.

25. Pipe Supports.—Great care must be exercised in hanging and supporting steam piping so as to take care of

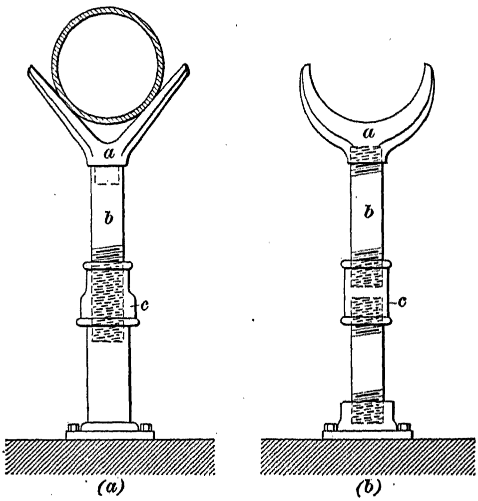


Fig. 20

the movement of the pipes due to expansion and contraction, to keep the pipe sections in proper alinement, and to provide for a rise or fall in the steam line so that the water formed by the condensation of steam will not flow back toward the boiler, in opposition to the direction of flow of the steam. The style of support will vary according to the piping arrangement. Pipe supports in general are standardized and may be classified as *hangers*, *standards*, and *brackets*. Hangers, shown in Fig. 19, carry the pipe overhead and are attached to rafters or other structural members in the frame of the

building. The hangers shown in (*a*) and (*b*) are adjustable within the limits of the length of the turnbuckles *a*. By this arrangement, short pipe lines can be raised or lowered to give a slight pitch to the piping. Rollers *b* are attached at the bottom of the brackets in (*b*) and (*c*) to allow the piping a lengthwise movement when expansion or contraction occurs.

26. Standards, as shown in Fig. 20 (*a*) and (*b*), are fixed to the floor and support the pipe saddles *a*, which are made

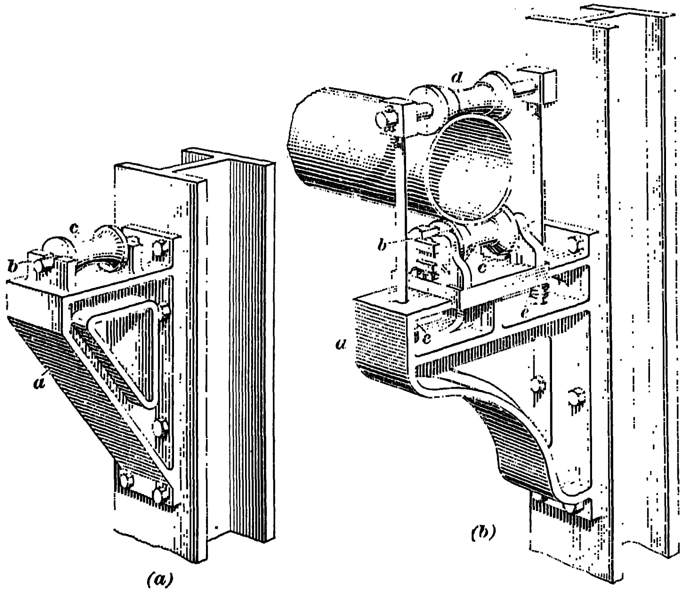


FIG. 21

V-shaped, as shown in (*a*), or are curved to fit the pipe, as in (*b*). The **V**-shaped support has the advantage that it can hold pipes of different sizes, whereas the curved support is suitable for practically only one size. The saddles can be raised or lowered by turning the pipe *b* up or down in the fitting *c*, which is threaded to receive the pipe. Standards are also made with rollers for supporting piping of great length.

Brackets are pipe supports that are attached to side walls and columns, as shown in Fig. 21 (*a*) and (*b*). Mounted on the

bracket *a* is a frame *b* that carries a roller *c*. For long piping of large diameter, the bracket shown in (*b*) is equipped with an upper roller *d*, which assists in maintaining proper alinement of the piping. To take care of the expansion of the pipe, and

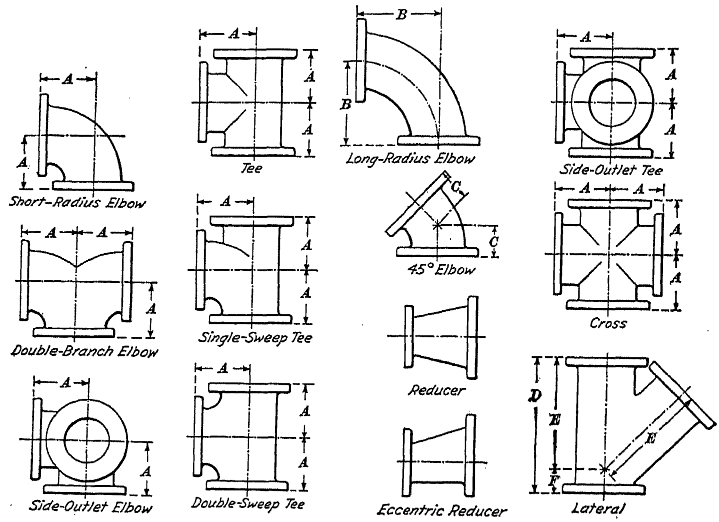


FIG. 22

at the same time hold the roller in position, springs *e* are installed at the bottom of the support rods for the upper roller.

27. Flanged Fittings.—American standard flanged fittings for the several classes of pipe are of the forms shown in Fig. 22. For standard pipe the face of the flange is plain, but the extra-heavy flange has a shoulder $\frac{1}{16}$ inch high, as shown in section in Fig. 23. These fittings are employed in making bolted pipe connections, where it is necessary to run the piping in different directions. The dimensions of the different flanges for pressures up to 125 pounds per square inch are given in Table VIII. The reference letters in Fig. 22 indicate the respective dimensions and correspond with those given in the table. Similar data for extra-heavy flanged fittings,

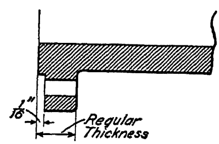


FIG. 23

TABLE VIII

AMERICAN STANDARD FLANGE FITTINGS

(For Working Pressures up to 125 Pounds per Square Inch)

Size of Pipe Inches	Dimensions of Fitting, in Inches						Size of Pipe Inches	Dimensions of Fitting, in Inches					
	A	*B*	*C*	*D*	*E*	*F*		*A*	*B*	*C*	*D*	*E*	*F*
1	3½	5	1¾	7½	5¾	1¾	8	9	14	5½	22	17½	4½
1¼	3¾	5½	2	8	6¼	1¾	9	10	15¼	6	24	19½	4½
1½	4	6	2¼	9	7	2	10	11	16½	6½	25½	20½	5
2	4½	6½	2½	10½	8	2½	12	12	19	7½	30	24½	5½
2½	5	7	3	12	9½	2½	14	14	21½	7½	33	27	6
3	5½	7¾	3	13	10	3	15	14½	22¾	8	34½	28½	6
3½	6	8½	3½	14½	11½	3	16	15	24	8	36½	30	6½
4	6½	9	4	15	12	3	18	16½	26½	8½	39	32	7
4½	7	9½	4	15½	12½	3	20	18	29	9½	43	35	8
5	7½	10¼	4½	17	13½	3½	22	20	31½	10	46	37½	8½
6	8	11½	5	18	14½	3½	24	22	34	11	49½	40½	9
7	8½	12¾	5½	20½	16½	4							

TABLE IX

AMERICAN EXTRA-HEAVY FLANGE FITTINGS

(For Working Pressures from 125 to 250 Pounds per Square Inch)

Size of Pipe Inches	Dimensions of Fitting, in Inches						Size of Pipe Inches	Dimensions of Fitting, in Inches					
	A	*B*	*C*	*D*	*E*	*F*		*A*	*B*	*C*	*D*	*E*	*F*
1	4	5	2	8½	6½	2	8	10	14	6	25½	20½	5
1¼	4¼	5½	2½	9½	7¼	2¼	9	10½	15¼	6½	27½	22½	5
1½	4½	6	2¾	11	8½	2½	10	11½	16½	7	29½	24	5½
2	5	6½	3	11½	9	2½	12	13	19	8	33½	27½	6
2½	5½	7	3½	13	10½	2½	14	15	21½	8½	37½	31	6½
3	6	7¾	3½	14	11	3	15	15½	22¾	9	39½	33	6½
3½	6½	8½	4	15½	12½	3	16	16½	24	9½	42	34½	7½
4	7	9	4½	16½	13½	3	18	18	26½	10	45½	37½	8
4½	7½	9½	4½	18	14½	3½	20	19½	29	10½	49	40½	8½
5	8	10¼	5	18½	15	3½	22	20½	31½	11	53	43½	9½
6	8½	11½	5½	21½	17½	4	24	22½	34	12	57½	47½	10
7	9	12¾	6	23½	19	4½							

carrying pressures from 125 to 250 pounds per square inch, are given in Table IX. The diameters of the flange and of the bolt circle, the thickness of the flange, and the number of bolt holes, for both standard and extra-heavy flanged fittings, are the same as for the corresponding sizes of companion flanges, and are given in Tables V and VI. Where it is necessary to run two pipes of different sizes from the same flanged fitting, a reducing tee, cross, or lateral is employed. The usual forms of these fittings are illustrated in Fig. 24. Flanged fittings may be made of cast iron, cast steel, or malleable iron.

28. Standard screwed fittings, such as tees, elbows, and laterals, are made for the smaller sizes of piping, and can be obtained in many different forms, threaded with right-hand

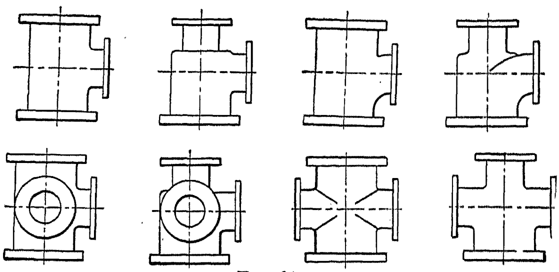


FIG. 24

threads. The size of a tee is designated by first stating the size of the run and then the size of the branch. The *run* is the line of pipe that enters and leaves the tee in the same straight line. Thus, the tee in Fig. 25 (a) has a 2-inch run and a $1\frac{1}{2}$-inch branch, and would be called a $2'' \times 1\frac{1}{2}''$ tee. If all the outlets of the tee had been for 2-inch pipe, it would have been termed a straight $2'' \times 2''$ tee, or simply a straight 2-inch tee. The tee shown in (b) connects pipes of three different diameters and is called a *reducing tee*. It is designated as a $1\frac{1}{2}'' \times 1\frac{1}{4}'' \times 1''$ reducing tee, the numbers being given in the order of their size, the largest first.

29. A lateral, or **Y**, having a branch at an angle of 45°, is shown in Fig. 25 (c). The method of designating the size of a lateral is the same as for a tee; thus, the lateral shown would

be called a $4'' \times 3'' \times 3''$ **Y**. The term **Y** *branch* is often used to designate this form of fitting. Laterals may be obtained in either standard or reducing-type sizes.

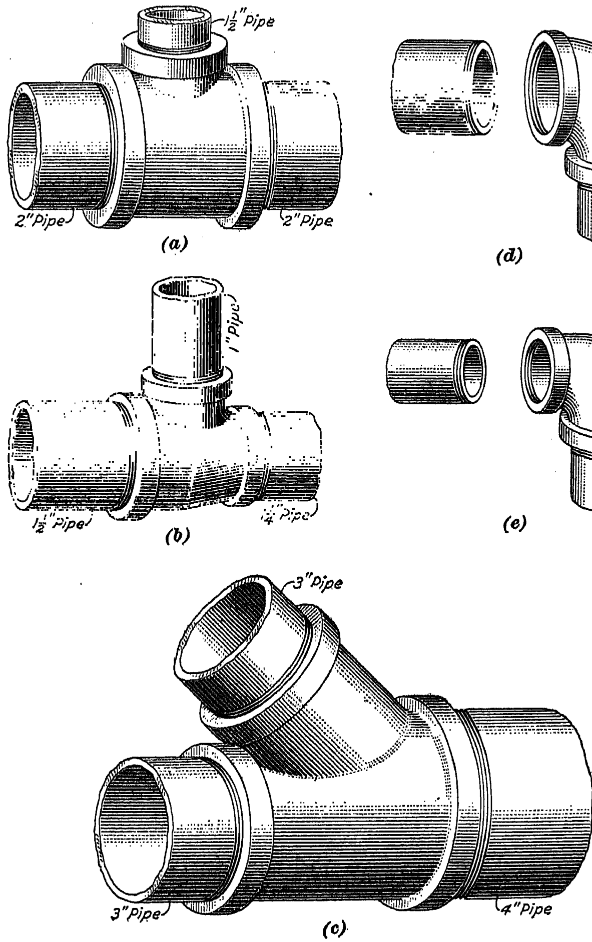


FIG. 25

The fittings shown in (*d*) and (*e*) are right-angle elbows, or 90° elbows, commonly termed *ells;* but elbows with the faces of the flanges at $22\frac{1}{2}°$, 45°, or 60° may also be obtained. The style of elbow in (*d*) may be had with either right-hand

or left-hand threads; or, the ends may be threaded in opposite directions. Reducing ells, of the type shown in (*e*), and, in fact, all other reducing fittings, have right-hand threads only.

VALVES AND COCKS

30. Globe Valves.—Valves are used to control the flow of water and steam in boiler piping. The bodies may be made of brass or iron, but the valve disks and seats are of composition

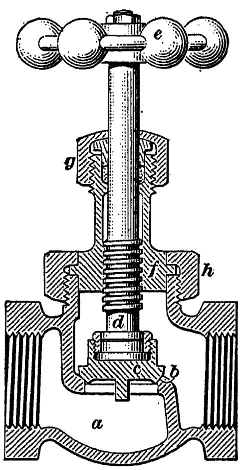


Fig. 26

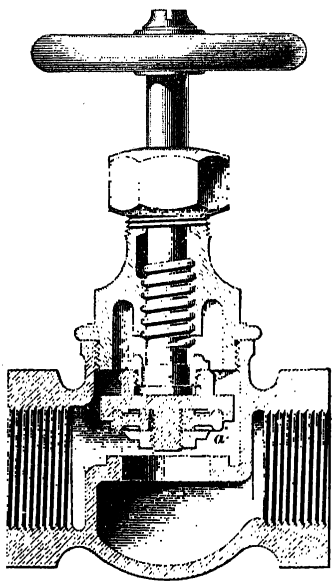


Fig. 27

metal. The working pressure and the kind of service determine the weight, size, and design of valve to be used. A sectional view of a globe valve such as is used on steam piping is shown in Fig. 26. The body *a* and the partition in which the seat *b* is formed are cast in one piece. The seat *b* is ground to a bevel to match the bevel of the valve disk *c*, which is fastened to the lower end of a threaded stem *d* carrying a hand wheel *e*. The threaded stem fits in a nut *f*, in the upper

end of which a stuffingbox is formed to prevent leakage of steam past the stem. The packing in the stuffingbox is compressed by screwing down the nut *g*. Turning the handwheel opens or closes the valve by raising the disk or forcing it down against its seat. The nut *f*, or *yoke* of the valve, is held to the body *a* by a nut *h*.

31. The globe valve shown in section in Fig. 27 has a brass body and a flat seat; but the valve disk *a* is a copper ring having two faces. Thus, if one face becomes worn or marred, so that the valve leaks, the disk may be turned over, bringing the other face into use. Metals softer than copper have been used for valve disks of this kind, but they have not proved so satisfactory. The use of the globe valve as a throttling device for regulating the flow of steam to a pump forms a severe service, because of the erosion of the seat and the valve disk. To overcome this trouble, a so-called throttling nut has been developed, which prolongs the life of the valve disk and seat. Valves of the types shown in Figs. 26 and 27 are made for pressures up to 250 pounds per square inch.

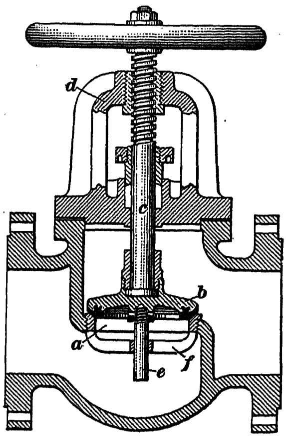


FIG. 28

A globe valve with an iron body is shown in Fig. 28. A brass seat *a* is screwed into the partition in the valve body and the valve disk *b* is made of brass, or of steel faced with brass. The threaded part of the stem *c* fits in a nut in the yoke *d*, the latter being flanged and bolted to the valve body. The small stem *e* slides in a guide in the spider *f* and serves to hold the disk central on its seat.

32. Angle Valve.—An angle valve having an iron body is shown in Fig. 29. The outlet *a* and the inlet *b* are at right angles, and the valve is used to connect pipes that meet at a right angle; hence, the valve is known as an angle valve.

The seat *c* is placed directly in the inlet opening, and as there are fewer changes of direction of the fluid passing through the valve, it offers less resistance to flow than does the globe valve shown in Fig. 26. Because the valve stem is long, a guide is provided in the form of a spindle *d* held in the spider *e*. The valve disk *f* is faced with brass. This valve is intended for large pipes that carry pressures of from 125 to 250 pounds per square inch.

33. Gate Valves.—Gate valves are made either as *single-gate valves*, which receive pressure on one side only, or as

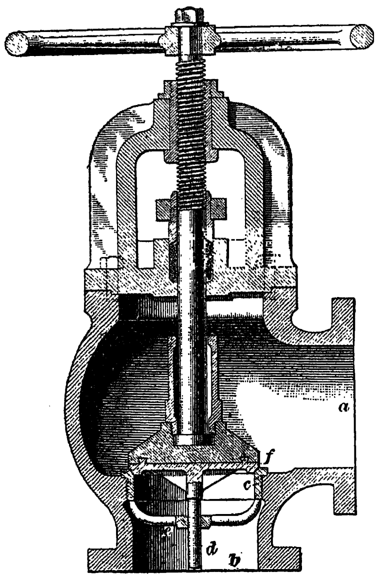


FIG. 29

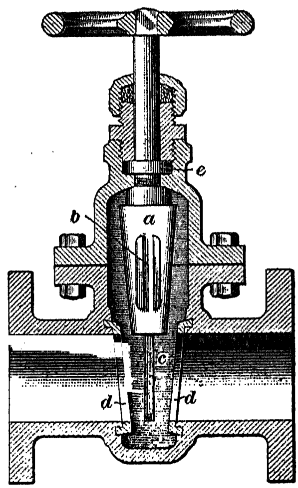


FIG. 30

double-gate valves, which may receive pressure on either side. Some forms of double-gate valves close the opening of the valve with a solid wedge; others close with a box wedge, and others with sectional gates having either parallel or wedge-shaped seats.

Gate valves are advantageous where little resistance to the flow of the liquid is desired, as they leave an unobstructed

passage when fully open. Therefore, they are largely used on water and exhaust-steam connections. When throttled, that is, only partly opened, they are hard to regulate and they often chatter. When they are used for steam, the seats should be made of bronze, which withstands high temperatures successfully. In all gate valves, the disks rise into the upper part of the body and bonnet to allow a straight passage for the liquid.

34. The valve shown in Fig. 30 is a double-gate valve with a tapering disk *a* machined flat on the sides and guided

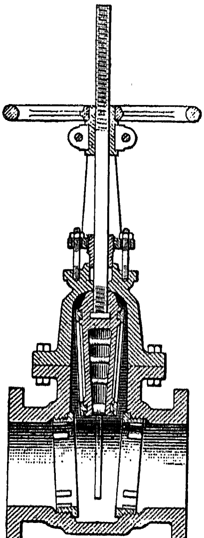


FIG. 31

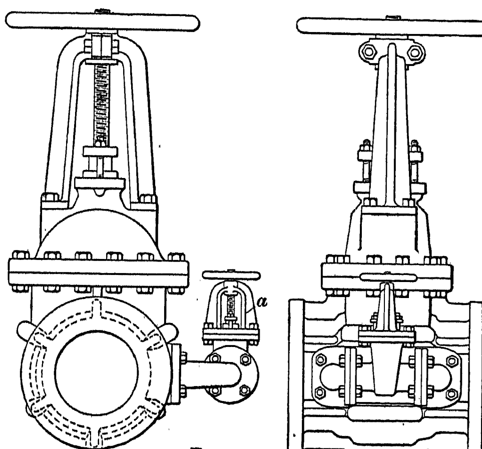


FIG. 32

by a slot *b* in each side of the disk, fitting over a guide *c* at each side of the valve body. The disk seats against soft metallic rings *d*, firmly embedded at each side of the opening and faced off to the same taper as the disk. The valve shown is an iron-body flanged gate valve. The lower end of the stem is threaded, and the disk travels on this thread, the stem being prevented from rising by the collar *e*.

35. For valves of 6 inches and upwards, on steam lines, it is desirable to use the outside-screw yoke type, with stationary wheel and rising spindle, as shown in Fig. 31. The advantages

of this type are that the extension of the stem shows the position of the gate, and that the screw can always be properly lubricated and does not come in contact with the steam.

By-passes are desirable on or around all live-steam valves of 6 inches and upwards. Fig. 32 shows a gate valve provided with a small by-pass valve *a*. By first opening the small valve, the pressures on the two sides of the disk are equalized, thus making the valve easy to open.

Gate valves should be installed in a vertical position, so that the regulating spindle is upright and the hand wheel on top. The valve should never be placed so that the hand wheel is on the bottom, because, when the gate is partly opened, a pocket is formed and the steam and water have a tendency to follow along the spindle and drip.

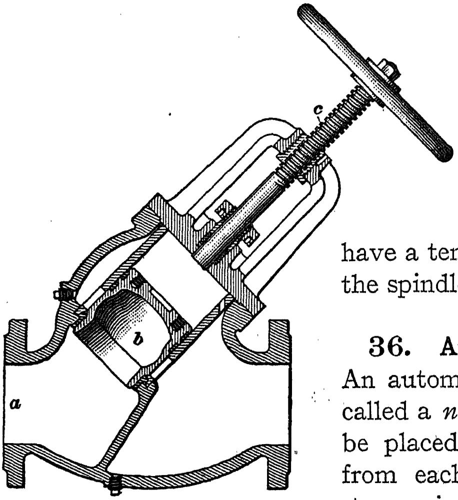


FIG. 33

36. Automatic Stop-Valve. An automatic stop-valve, often called a *non-return valve*, should be placed in the pipe leading from each boiler to the main steam pipe, when two or more boilers are connected in a battery. If one of the boilers becomes sluggish in generating steam, its stop-valve will close automatically and will remain closed until the pressure in the sluggish boiler has been built up to that existing in the main, when the valve will open. Such a valve is a protection against accidents. If one of a battery of boilers has a blown-out tube, or any other mishap that suddenly lowers the pressure, the stop-valve closes and prevents the steam from backing into the damaged boiler from the main pipe. If a boiler is undergoing repairs, the presence of such a valve on its steam line is a safeguard

against admission of steam while workmen are engaged on the boiler. The stop-valve shown in Fig. 33 is built for pressures up to 250 pounds per square inch. It is connected with the inlet *a* faced toward the boiler, so that the boiler pressure acts under the valve *b* and raises it until the ports in the surrounding sleeve are uncovered. The steam then passes through these ports and out of the valve into the steam line. The space above the valve is subjected to the pressure in the steam line because of the small opening through the side of the sleeve just beneath the valve cover. If the pressure in the boiler becomes less than that in the steam line, the pressure in the upper end of the sleeve, above the valve, will force the valve to its seat, and thus prevent

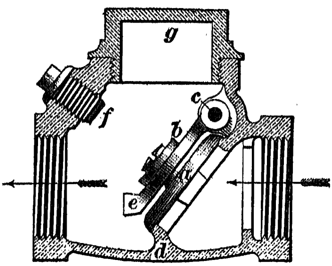


FIG. 34

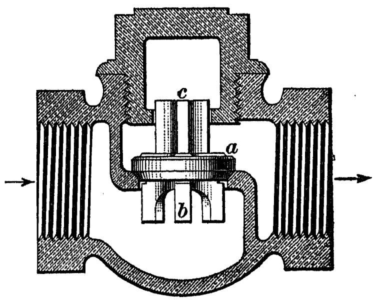


FIG. 35

steam from flowing back into the boiler from the line. When it is necessary to close the valve by hand, to cut out the boiler, or to test the automatic action of the valve, the spindle *c* is screwed down until the valve is forced into its closed position. In addition to the automatic stop-valve, a gate valve should be installed in the steam piping between the boiler and the main steam pipe. Ample drains must be provided for such valves, if water can accumulate in them.

37. Check-Valves.—Check-valves are valves that permit fluids to pass through them in one direction only; they are designed so as to close automatically whenever the flow of the fluid is reversed. They are made in different forms, as vertical, horizontal, and angle check-valves.

38. The check-valve shown in Fig. 34, known as a *swing check-valve*, may be used in either a horizontal or a vertical pipe. The valve disk *a* is attached to an arm *b* hinged at *c*. The disk and arm are so connected as to permit a slight movement of the disk so that it will close on the seat *d* properly. The lug *e* on the arm strikes the screw *f* when the disk is swung open, thus preventing it from swinging too far. The screw cap *g* covers the opening that gives access to the valve for inspection. The direction of flow of the fluid is indicated by the arrows. This type of check-valve probably offers less resistance to the passage of a fluid than any other form.

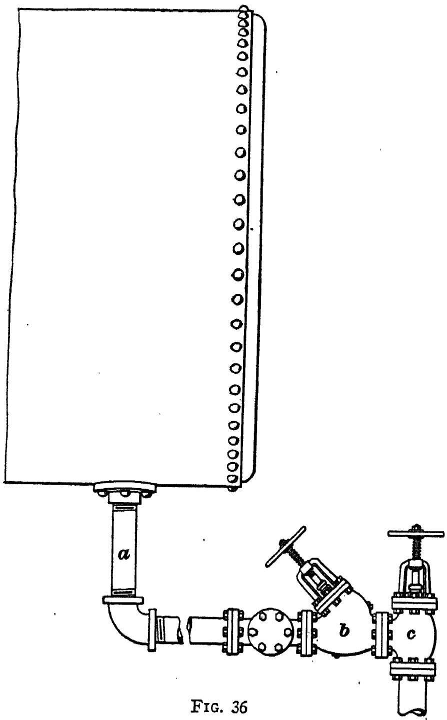


FIG. 36

39. In Fig. 35 is shown a *globe check-valve*, the form most commonly used. The disk *a* is provided with wings *b* on the bottom and a guide *c* on the top to keep the valve from tilting sidewise. Special forms of these types of valves are made to take the place of elbows in pipes. In such cases, they are known as *angle check-valves*.

40. Blow-Off Valves and Cocks.—The blow-off pipe is connected to the bottom of the boiler or mud-drum, or at the lowest part of the water space. Its purpose is to drain the boiler, as well as to remove scale, mud, and other sediment that collect at the bottom of the boiler. The blow-off con-

nections for a return-tubular boiler are shown in Fig. 36. The blow-off pipe *a* is carried straight down through the combustion chamber and then out through the setting, being fitted with a **Y** blow-off valve *b* and an angle blow-off valve *c*. With this arrangement, the pipe *a* should be protected from the hot gases by cast-iron sectional sleeves clamped around it; or, a firebrick pier of **V** section should be built in front of the pipe, the angle of the **V** pointing forwards and the pipe *a* being inside the angle formed by the wing walls. As blow-off valves are repeatedly opened and closed, they are subject to rapid wear, or cutting, by the escaping water, dirt, and scale. This cutting is noticeable particularly when the steam pressures are high, for then the escaping current has a high velocity through the valves. Blow-off pipes extending through combustion chambers should be of genuine wrought iron and extra heavy.

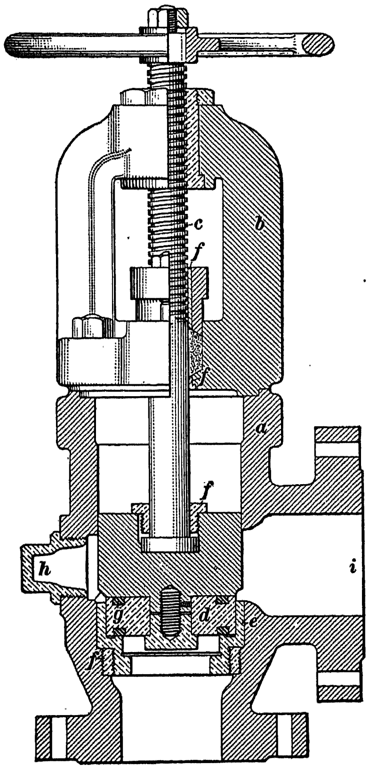


FIG. 37

41. Owing to the frequent use of the blow-off valve and the danger of its working parts becoming damaged, the necessity of additional protection is apparent. On all new boiler installations, the A. S. M. E. Boiler Code prescribes the rule that where the steam working pressure is above 125 pounds per square inch, the blow-off from any pipe line shall have two valves, or a valve and a cock, of extra-heavy pattern, arranged in the piping. The minimum size of pipe shall not be less than 1 inch

in diameter and the maximum not over $2\frac{1}{2}$ inches in diameter. No reducing fittings are permitted in the line, as the piping must run full size its entire length. A blow-off valve or cock must be absolutely tight to prevent leakage, and should also be capable of being opened and closed easily. It must also be constructed of materials that will withstand the severe service to which it is subjected. Ordinary steam globe valves are not suitable for connections of this kind.

42. A very good form of angle blow-off valve is shown in Fig. 37. The body *a* and yoke *b* are made of iron, and the working parts, such as the valve stem *c*, the valve disk *d*, the valve seat *e*, and the bushings *f*, are made of bronze. In the valve disk *d* are seating surfaces *g* made of an alloy that, being softer than the valve seat, will yield to any irregularities and make a tight connection. At the back of the valve is a clean-out plug *h*, which is removable, permitting the insertion of a rod into the valve for clearing away sediment, scale, etc. that may accumulate in the inlet *i*. All angle valves should be connected so that the inlet or side opening *i* is toward the boiler and thus have the pressure on top of the valve disk. This arrangement protects the valve disk and the valve seat from the direct impact of the steam and sediment. The valve should be opened wide when the boiler is blown down, so as to reduce as much as possible the wear on the seat and disk.

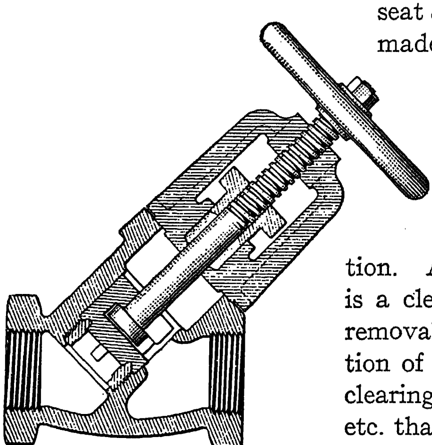


FIG. 38

The **Y** blow-off valve, Fig. 38, is sometimes placed in the run of piping between the boiler and the angle blow-off valve, as shown at *b*, Fig. 36. The valve shown in Fig. 38 is of special design, and constructed of a hard, non-corroding

material. It should be installed so that the pressure is exerted on top of the valve disk.

43. A blow-off cock is generally used in connection with a blow-off valve, serving the same purpose as the **Y** valve and being located in the same position as the **Y** valve in Fig. 36. The construction of the cock is shown in the sectional view, Fig. 39. It consists of an extra-heavy body *a* and a tapered plug *b* that is ground to its seat in the body to produce a tight joint. The compensating spring *c* is located between the plug *b* and the clean-out cap *d*, its purpose being to take up the wear and to hold the plug securely to its seat at all times, thus preventing sediment and scale from collecting around the bearing surfaces of the plug and seat. An opening is formed in the plug from side to side, and the water passes straight through it when the opening is turned parallel with the run of the piping. The handle *e* is for the purpose of turning the plug to open and close the cock. Blow-off cocks are made with either screwed or flange connections.

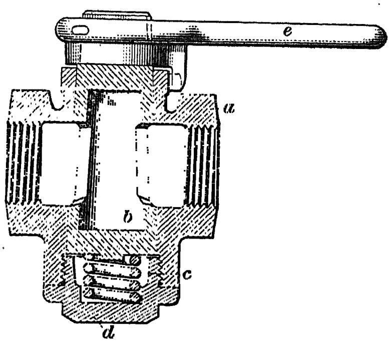


FIG. 39

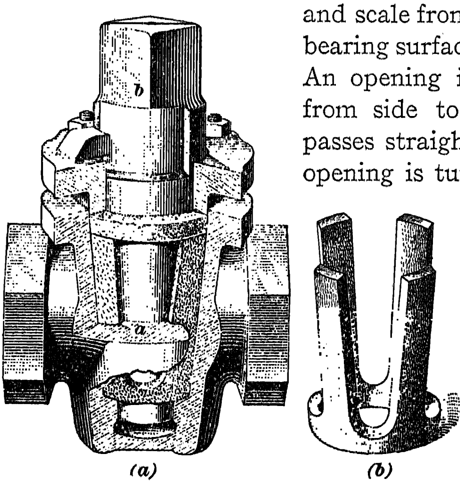


FIG. 40

44. An asbestos-packed blow-off cock is shown in Fig. 40. The **U**-shaped grooves *a* are cast in the interior surface of the body, forming a seat for asbestos. The asbestos packing is elastic

and makes a tight joint, and at the same time allows the plug *b* to be turned easily. For a top packing a vulcanized composition ring is used. The form of the asbestos packing contained in the **U** grooves is shown in (*b*). Since the asbestos is not affected by heat or moisture, this form of cock is durable. In blowing down a boiler the **Y** valve or blow-off cock is opened first, and then the angle blow-off valve. After the boiler is blown down, the angle valve is closed first, and then the **Y** valve or blow-off cock.

45. Pressure-Reducing Valves.—When steam is required at a lower pressure than that at which it is supplied by the boiler, some form of pressure-reducing valve must be used. A reducing valve, designed to give a uniform low pressure from a varying higher pressure, is shown in Fig. 41. The steam flows through the valve from the inlet *a* to the outlet *b*, as shown by the arrows. When it is desired to use it as an angle valve, the outlet may be made at *c*. The flow of the steam is impeded and its pressure reduced by means of two disks *d* and *e* covering the ports in the interior of the valve body. These disks are connected by the sleeve *f* and are rigidly attached to the valve stem, so that the ports are opened by the downward movement of the valve stem and closed by the upward movement. Each disk is guided by four wings on its upper side, and by the valve stem, which passes through a hole in the bonnet *h*.

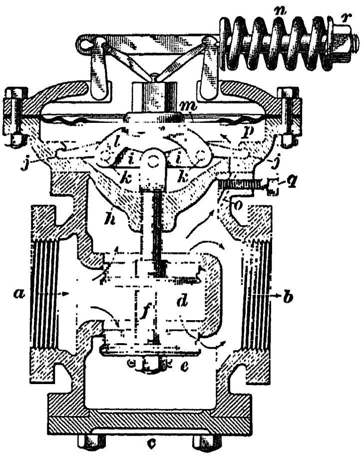


FIG. 41

46. The upper end of the stem, Fig. 41, is connected to the inner ends of two levers *i* that have their fulcrums *j* in the flange of the bonnet. The levers are pivoted on pin connections *k* in the ends of a yoke *l*. The yoke is attached to the

center of a corrugated circular copper diaphragm *m*, which is subjected to the steam pressure beneath and the action of a spring *n* on top. The amount of steam flowing through the port *o* is regulated by means of a screw *q*. The resistance of the spring *n* is regulated by a nut *r*. The valve not only reduces the pressure, but also regulates it automatically; that is, although the boiler pressure may vary considerably, as long as it does not fall below the pressure for which the valve is set, the valve will give a practically uniform pressure on the discharge, or low-pressure, side. The pipe on the low-pressure side of the valve should be fitted with a steam gauge.

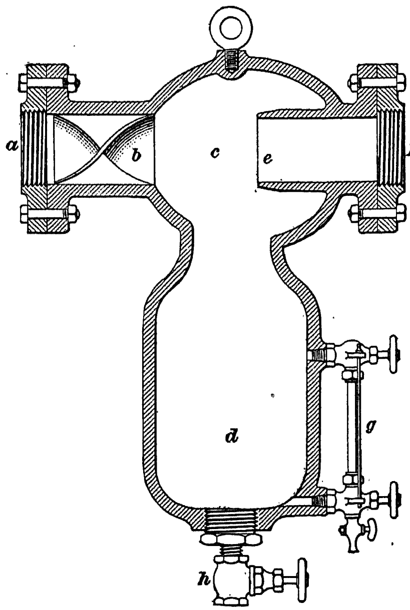


FIG. 42

STEAM-PIPING ACCESSORIES

47. Separators.—A steam separator is a device designed to remove the entrained water, oil, dirt, and other impurities from a current of steam flowing through a pipe. When it is intended merely to free the steam from water, the separator is placed on the main pipe leading from the boiler to the engine, and as close as possible to the latter. When grease and dirt are to be removed from exhaust steam before it is condensed and fed back to the boiler, the separator is placed in the exhaust pipe leading from the engine to the condenser.

48. Classes of Steam Separators.—Steam separators may be divided into two general classes: *centrifugal separators* and *baffle-plate separators*. In a centrifugal separator, the

steam is given a whirling motion, so that the water held in suspension in the steam is thrown outwards by centrifugal force against the walls of the separator. In a baffle-plate separator the steam comes in contact with plates generally placed at right angles to the direction of flow of the steam. The plates abruptly change the direction of the steam current. Either type of separator causes the particles of water to be thrown out of the steam current, and on striking the walls of the separator, the water is led away to a drain. The dry steam passes through the separator to the main piping.

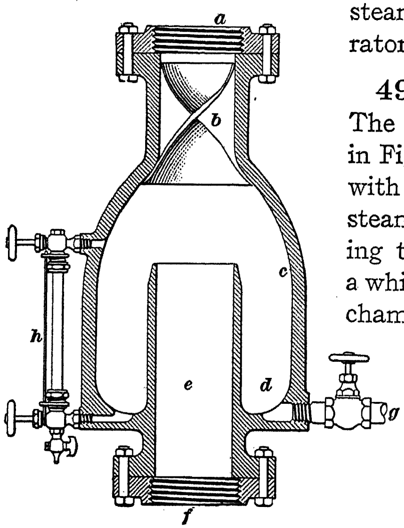


FIG. 43

49. Centrifugal Separator. The centrifugal separator shown in Fig. 42 is arranged to connect with horizontal piping. The steam enters at *a*, and on striking the curved baffle *b* is given a whirling motion as it enters the chamber *c*. The particles of water are thrown off by the centrifugal action, run down the walls of the separator, and collect in the chamber *d*. The steam current is reversed, flows over the edge of the projecting pipe *e*, and escapes at *f*. A gauge glass *g* is provided to show the amount of water that has collected, and a drain pipe *h* to remove the water.

50. The vertical centrifugal separator shown in Fig. 43 operates like the horizontal type. The flange *a* is connected to the boiler side of the vertical piping. The steam flows down over the baffle *b*, by which it is given a whirling motion. The whirling of the descending current throws the particles of moisture outwards against the wall *c* of the separator, from which they trickle down and collect in the chamber *d*. The steam escapes by way of the passage *e* to a pipe connected at *f*.

The moisture is drained away through the valve *g*. The gauge glass *h* shows the depth of water collected in the chamber *d*.

51. Baffle-Plate Separator.—In the baffle-plate separator shown in Fig. 44 (*a*) and (*b*) the steam enters at *a* and is deflected outwards at right angles by the baffle *b*, which is deeply grooved on its face. The water in the steam is caught in the grooves *c*, flows down them to the bottom and drips into the chamber *d* of the separator. The steam flows out around the sides of the baffle through the ports *e* into the chamber *f*. Here it strikes the curved wall *g* of the separator and is thrown back against the opposite face of the baffle *b*, which removes further moisture. This moisture drips through the pipe *h* and so cannot be picked up again by the steam, which escapes at *i*. The water collecting in the chamber *d* is drained off at *j*, the level being indicated by a gauge glass attached at *k*.

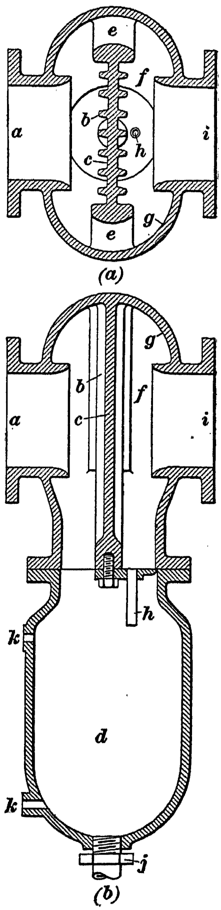


FIG. 44

52. Drip Pockets.—Attachments known as drip pockets are sometimes installed to collect water, dirt, grease, and other substances that accumulate in steam piping. As shown in Fig. 45, a drip pocket is simply a collecting chamber *a* connected to a tee *b*. The chamber is fitted with a glass gauge *c* and a drain pipe *d*. Drip pockets are made in sizes up to 12 inches in diameter, and the flanges are made to fit either standard or extra-heavy fittings.

53. Exhaust Heads.—Exhaust heads are separators placed on exhaust-steam piping from non-condensing engines or pumps to prevent the water in the escaping steam from being thrown on the roof or on adjoining build-

ings. Such devices also serve as mufflers, deadening the sound of the exhaust. Exhaust heads are made of steel plate or cast iron, that shown in Fig. 46 being a typical steel exhaust head. The exhaust steam enters at *a* and travels in the direction of the arrow until it strikes the inverted conical surface *b* and the walls of the cylinder *c*. A drip through *d* around the base of the cylinder *c* collects the water that flows down its surface.

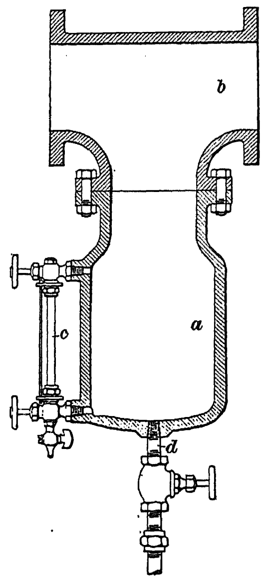


FIG. 45

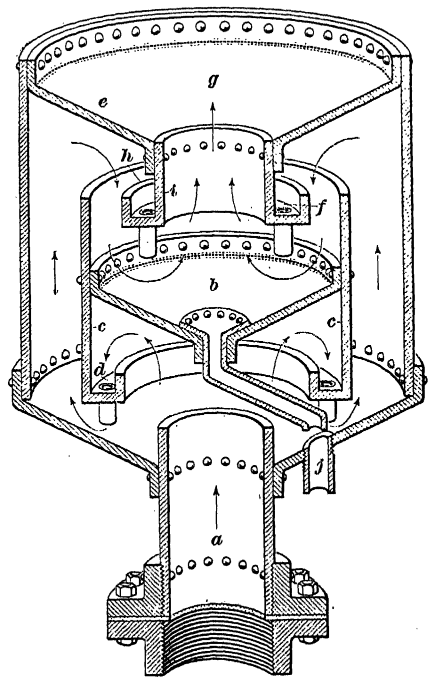


FIG. 46

The steam flows down and out at the bottom of the cylinder *c* and rises until it strikes a second inverted cone *e*, on which it deposits additional water. This water follows the surface of the cone and drips into the trough or gutter *f*. The steam passes out at *g* to the atmosphere after flowing over the top edge of the cylinder *c*, past the lip *h*, and up through the cylinder *i*. Drip pipes installed at the bottoms of the gutters carry the water to the outlet *j*, thus draining the water from the exhaust head.

STEAM TRAPS

54. Purpose of Steam Trap.—If no means were used to remove the condensation from steam pipes, the water might be carried into pump or engine cylinders and damage them; or, it might be picked up by the swiftly moving steam current and produce water hammer, which might wreck the pipe or the fittings. The steam trap is a device that removes accumulated condensation from drip pockets or separators attached to steam pipes under pressure, without allowing steam to escape. Its action is intermittent and automatic.

55. Classes of Steam Traps.—There are two general classes of steam traps: *open*, or *discharge*, *traps;* and *return*, or *closed*, *traps*. An open trap, or discharge trap, empties the water of condensation into a sewer or a tank. A return trap, or closed trap, delivers the condensation to the boiler from which it came as steam. Steam traps are also named according to the means by which they are operated, being known as bucket traps, float traps, tilting traps, and expansion traps or thermostatic traps.

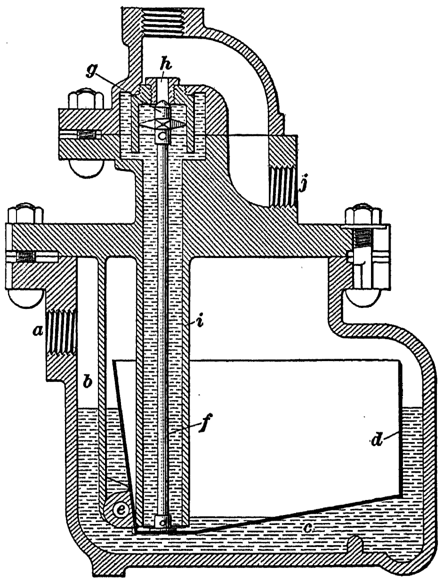


FIG. 47

56. Bucket Trap.—The bucket trap shown in section in Fig. 47 is an open steam trap. Condensation from the steam pipe enters at *a*, flows through the passage *b* and collects in the body *c* of the trap. A bucket *d* is hinged on a pin *e* and is connected by a rod *f* to a valve *g* that opens and closes outlet *h*

from the trap. As the condensation collects in the body of the trap, the empty bucket tends to float and swings upwards on its pin *e*, thus forcing the valve *g* against its seat and closing the outlet. The condensation accumulates and eventually spills over the edge of the bucket and collects in the bucket, which promptly sinks and opens the valve *g*. The interior of the trap is subject to the pressure existing in the steam pipe, and this pressure forces the water inside the bucket to flow up inside the sleeve *i*, through the opening *h*

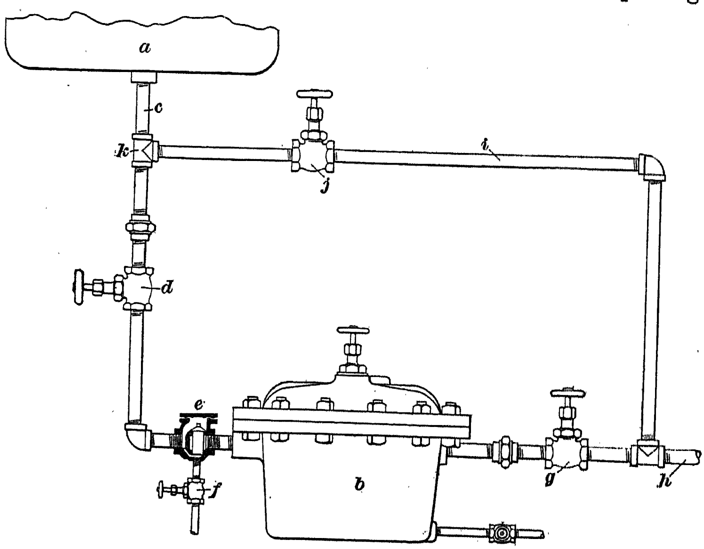


FIG. 48

and out through the discharge at *j*. When the bucket is nearly emptied, its buoyancy causes it to float, and in rising it again closes the valve *g* and prevents the escape of steam.

57. Steam-Trap Connections.—An example of the way in which a steam trap may be connected is shown in Fig. 48. The condensation from the steam pipe runs into a drip pocket *a*, from which it drains into the steam trap *b* through a pipe *c*, valve *d*, and strainer *e*. The strainer prevents the entrance of anything that might clog the trap. It may be flushed out by opening the valve *f*. On the discharge side of the trap is a

valve *g* in the pipe *h* leading to the sewer. A by-pass pipe *i*, fitted with a valve *j*, is installed between the tee *k* and the pipe *h*. If the trap must be repaired or cleaned, the valves *d* and *g* are closed and the valve *j* is opened sufficiently to drain off the water as fast as it accumulates in the drip

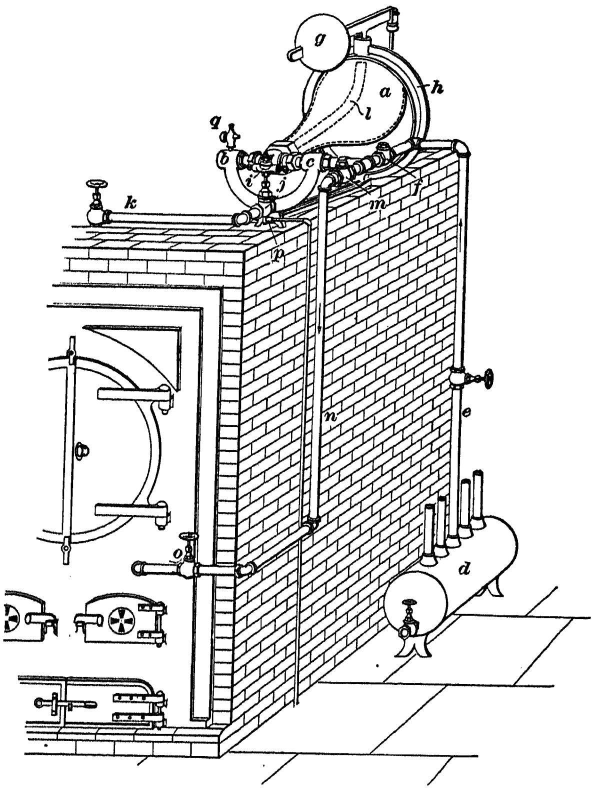


FIG. 49

pocket; but under normal operation the valve *j* is closed and the valves *d* and *g* are open.

58. Tilting Trap.—To return water of condensation to the boiler, a return trap is employed. It must be located at such a height above the water in the boiler that the hydrostatic head produced by the elevation of the trap will cause the water

of condensation to flow into the boiler. One form of return trap, known as a tilting trap, with the necessary piping and valves to connect it to a boiler, is shown in Fig. 49. It consists of a cast-iron receiver *a* supported at one end by hollow trunnions *b* and *c* on the stationary part of the trap and at the other end by a link, a lever, and a weight *g*. In the drainage of a heating or steam-pipe system, the different return pipes lead to a tank, as shown at *d*. The water rises through the pipe *e*, and passes through the check-valve *f* and trunnion *c* to the receiver *a*. The water enters this receiver until its weight is sufficient to overbalance the counterweight *g*, when the receiver *a* moves downwards until it comes against the guide *h*. This downward motion causes the lug *i* to engage the upper nuts on the stem of the steam valve *j*, opening the latter and thus admitting steam at full boiler pressure on top of the water. Steam enters from the boiler through the pipe *k*, trunnion *b*, and curved pipe *l*, leading to the highest point in the receiver. Driven by the steam, the water flows from the receiver to the boiler by gravity, through the trunnion *c*, check-valve *m*, pipe *n*, and globe valve *o*. As soon as the receiver is emptied, the weight *g* lifts it to its upper position, which closes the steam valve *j* and opens a small air valve *p* below the valve *j*, allowing the steam to exhaust from the receiver. A cock *q* is provided on the trunnion *b* for the purpose of venting the interior of the receiver by hand, if necessary at any time.

59. When there is not sufficient pressure to make the water in the receiver enter the trap on top of the boiler, another trap may be placed at the point where water will flow into it. This trap may then be made to discharge into one placed on top of the boiler, using steam from the boiler as a motive force.

Return traps can be made to discharge the water into elevated tanks, the height to which the water may be raised depending on the available boiler pressure. This height, in feet, allowing for frictional and other resistances, is given approximately by multiplying the boiler pressure available by 1.4. Thus, if the boiler pressure is 60 pounds per square inch, a return trap can discharge into a tank $60 \times 1.4 = 84$ feet above it.

60. Float Trap.—The float trap shown in Fig. 50 depends for its action on the rising and falling of a float *a* that controls the opening and closing of the valve *b*, through which the water is discharged. The valve is connected to the float by a series of levers *c*, and the higher the float rises, the wider the valve

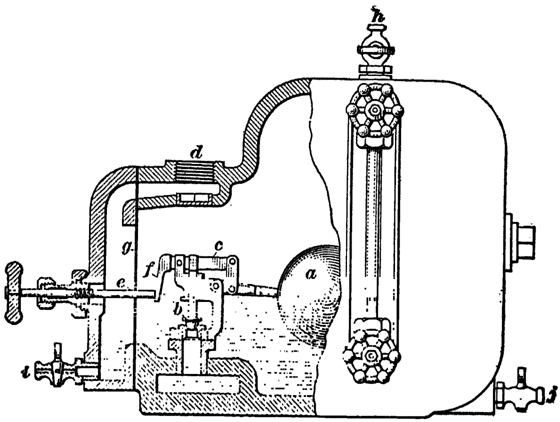


FIG. 50

opens and the greater the rate of discharge. Thus, if the condensation enters the trap at *d* at a fairly uniform rate, the discharge will occur at the same rate and the operation will be continuous. To prevent the weight of the float from forcing the valve too hard against its seat, an adjustable stem *e* may be screwed inwards until it bears against the bent arm *f* on the lever that moves the valve. A strainer *g* prevents the passage of dirt that would clog the valve. Air may be removed through the vent *h* and sediment through the cocks *i* and *j*.

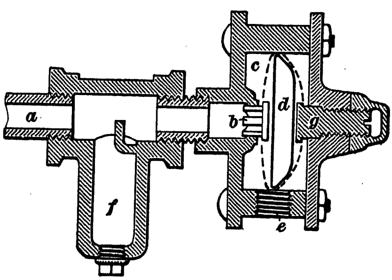


FIG. 51

61. Thermostatic Trap.—The thermostatic steam trap depends for its action on the expansion and contraction of a part

under the effect of heating and cooling. One form is shown in Fig. 51. The condensation enters by way of the pipe *a*, flows past the valve *b*, and collects in the chamber *c*, which contains an air-tight circular vessel *d* made of thin sheet metal. The water escapes from the chamber *c* through the outlet *e*. When most of it has escaped, and hot water or steam enters the chamber *c*, the heat causes the air in the vessel *d* to expand, and the flat sides bulge out, as indicated by the dotted lines. The valve *b* is pushed against its seat by this bulging of the vessel *d*, and the flow is stopped until the collected water cools and the vessel *d* contracts enough to open the valve. With a uniform rate of condensation, the action of the trap is practically continuous. A dirt pocket is provided at *f*, and an adjusting screw at *g* to alter the quickness with which the valve is closed. The thermostatic trap is not likely to freeze or become air-bound.

62. Suggestions for Trap Installations.—The size of trap to be used depends on the volume of water of condensation to be handled and is not based on the size of the pipe to which it is attached. There are several rules to be followed in the installation of a trap: The trap must be located at a low point in the return piping, so that the water of condensation will flow to it by gravity. Means must be taken to prevent the trap and piping from freezing; for, when a trap is blocked with ice, the valves will not work and the water will back up in the return piping. By-pass piping should be so installed that, in case the trap must be cleaned or repaired, the condensation may be discharged through the by-pass.

DESIGN AND ARRANGEMENT OF PIPING

PRINCIPLES OF DESIGN

63. General Requirements.—The installation of a complete steam plant includes the setting of the boiler or boilers, the arrangement of the various lines of piping, and the location and arrangement of the various accessories, such as feedwater heaters, purifiers, separators, economizers, feed-pumps, and

injectors. An elaborate plant may be fitted with economizers, mechanical stokers, coal conveyers and ash conveyers, purifiers, and other labor-saving and fuel-saving devices. On the other hand, the plant may consist simply of boilers, chimney, and feed-pump.

The proper designing of a system of piping requires a careful analysis of the conditions of service, a thorough knowledge of the methods of distributing and conveying steam and water, and of the quality and strength of materials employed. A system of steam piping for a power plant must be so designed as to insure reliability of service and economy of construction. The main lines of piping should be so connected that it will not be necessary to shut down the entire plant to make minor repairs. Continuity of operation is absolutely indispensable to a successful power plant.

64. Drainage.—The pipes and fittings must be so proportioned as to permit a free flow of steam or water, so that no undue loss will be caused by condensation, radiation, or friction. The steam piping should be so arranged that water pockets will be avoided; and where such pockets are unavoidable, they must be drained to free them from water. The entrained water can be automatically returned to the boiler. By-pass pipes, with suitably placed valves, should be arranged around feedwater heaters, economizers, pumps, etc. The system must be so designed as to give perfect freedom for expansion and contraction, without undue stress on any part of the system, and without opening joints and thus causing leakage. An elaborate duplication of steam mains and connections is not necessary. The double, or duplicate, system of piping was introduced to insure continuous power-plant service, which would not be obtainable with single piping. Reliability is insured by careful design and superior workmanship, combined with the use of high-class materials and fittings and the judicious placing of cut-out and by-pass valves.

65. Drainage.—Perfect drainage must be provided in order that all water of condensation shall be fully separated

from the steam, and, by suitable traps or return systems, delivered again to the boiler. Drainage is best effected by arranging the piping so that all the water of condensation will flow by gravity toward a point close to the delivery end of the pipe, and then providing a drip pipe at that point. In the case of large pipes, a trap may be placed at the end of the drip pipe for automatic draining; the trap serves to seal the end of the drip pipe and thus prevents waste of steam.

66. Water Hammer.—The presence of water in a steam pipe is the cause of water hammer, the term used to describe the condition that causes the hammering noise often heard in the piping of steam-heating plants. It has been shown experimentally that the pressure produced by water hammer may be as great as ten times that which the pipe is expected to sustain in its regular work. In some cases, water hammer has caused boiler explosions by bursting a steam pipe and thus relieving the boiler pressure so suddenly that a large quantity of water flashed into steam.

67. Condensation and Friction.—When steam leaves the boiler and flows through a pipe to the point where it is to be used, it loses a part of its original energy. Some of its heat is lost by radiation, conduction, and convection, and if the steam is not superheated, this loss of heat results in condensation of part of the steam. It takes place whether the steam is flowing or at rest, but it may be reduced to a minimum by using non-conducting coverings on the pipes.

Because of friction in flowing through pipes and fittings, the pressure of steam at the outlet, or discharge, end of a system of piping is less than at the inlet, or boiler, end. The loss of pressure due to friction reduces the flow below the estimated capacity of a straight pipe, and must be taken into account in the case of a long pipe with numerous bends and fittings.

Friction is greater through elbows of short radius than through elbows of long radius, because the change of direction of flow is more abrupt. It is advantageous, therefore, to make all bends of large radius. Globe valves offer considerable

resistance to the passage of high-pressure steam, but the drop in pressure when passing through a gate valve is practically negligible.

ARRANGEMENT OF PIPING

68. General Requirements.—In arranging a piping system for a steam plant, the aim must be to produce a design that combines low first cost with durability and serviceableness. A point that must be considered is the extent to which the piping must be in duplicate in order to prevent a shut-down in case of an accident to any section. The ease with which the piping can be taken down for repairs must also be considered. In general, flanged sections are more easily taken down than sections united by screwed joints, at least in the larger sizes. When screwed joints are used, it is advisable to introduce a liberal supply of unions, so that a section may be taken out and replaced without having to tear down the whole piping system. The question of whether to place the piping overhead or under the flooring is chiefly one of convenience and appearance. With the piping under the flooring, the engine room will generally look better, but the piping will not be as accessible as when overhead.

69. Careful thought is necessary in designing piping connections to boilers. Connections between a single boiler and the distributing main are comparatively simple to make; but when two or more boilers are to be connected to the same main line of pipe, special and adequate provision must be made for expansion; otherwise, the stresses on the connections will cause them to leak. If a long line of pipe is connected directly to the boiler shell, the expansion due to the entrance of hot steam will so increase the length of the pipe as to twist or wrench the joints and cause them to leak.

70. Connecting Main Steam Pipe to Boiler.—Several approved methods of connecting the main steam supply pipe to the boiler are shown in Figs. 52 and 53. In Fig. 52, the connections are made by means of bent pipe, while in Fig. 53 straight pipe is used. In Fig. 52 (*a*) and (*c*), a short

length of pipe rises vertically above the shell of the boiler and connects with a bent branch pipe joined to the main steam pipe or header, the bent pipe allowing the header to expand and contract freely. In (*b*), connection between the boiler end and the header is made by using a **U** bend; and (*d*) illustrates the use of two quarter-turn bends in making the connection. It is generally conceded that, when pipe bends are thus used, the best position for the valve, when only one is used, is at the center of the bend; but some engineers regard

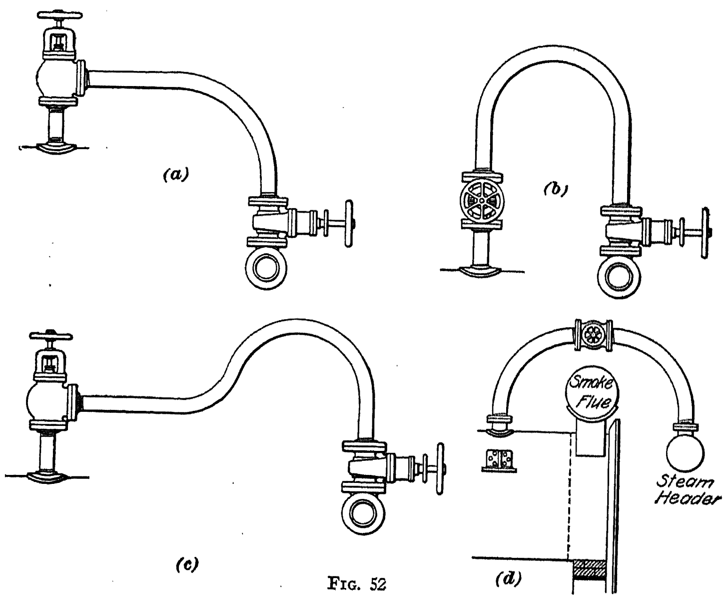


FIG. 52

it as better practice to use two valves, one being placed near the main and the other at the boiler. When two valves are used, it is frequently necessary to tap the body of each valve for a drip connection to drain away any water of condensation that may accumulate in it.

71. In Fig. 53, in which a straight pipe *a* is used, the length of the vertical sections should be great enough to give the spring necessary to allow for expansion without straining any of the pipe parts and fittings. The branch pipe *b* is the

steam main, or header, and *c* is an angle gate valve. In high-pressure steam plants, it is customary to insert, in addition, an automatic stop-valve *d* in the branch from each boiler to the steam main. Its object is to prevent, automatically, the flow of steam from one boiler to any boiler that may be disabled. The non-return valve illustrated is similar to an ordinary angle globe valve, except that the valve disk *e* has sufficient vertical play on the lower end of the stem *f* to allow it to seat, should the pressure in the individual boiler become

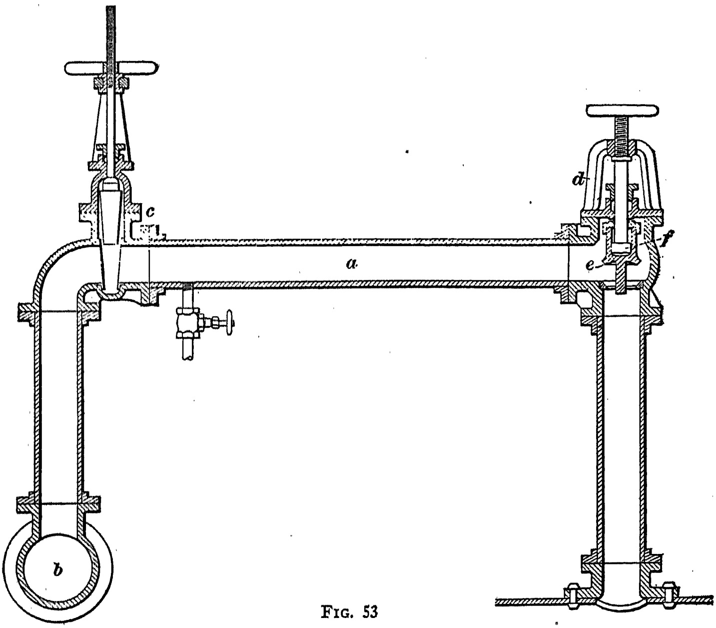


FIG. 53

much less than that in the main, even when the valve stem is in its highest position. The arrangement is such that the disk may be firmly held to its seat when desired. Gate valves are not suitable for this kind of emergency work, as they require considerable time to close, and may be difficult to move when nearly closed.

72. When several boilers of, say, 200 horsepower and upwards are used, it will be found very convenient to place

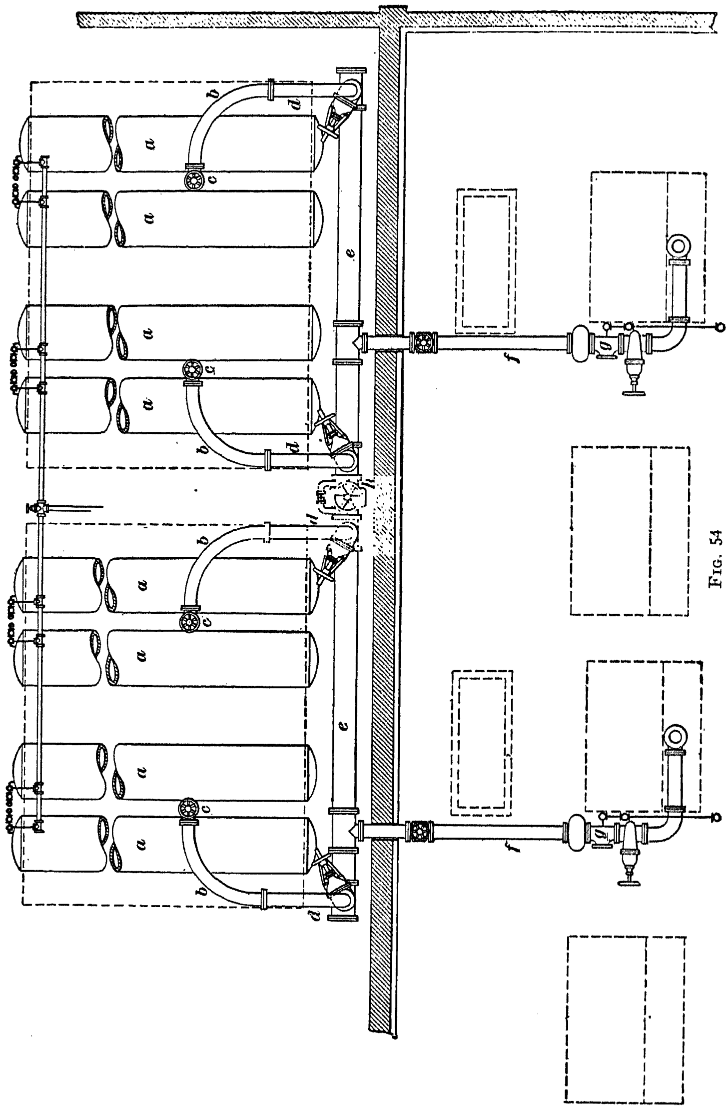


FIG. 54

the steam main or header on or near the floor in the rear of the boilers; this brings all the large valves in accessible positions. The steam lines leading to the engines are placed below the engine-room floor. This system is particularly applicable where horizontal engines are used.

73. The judicious use of long-radius bends, a convenient arrangement of valves, accessible location of the live-steam

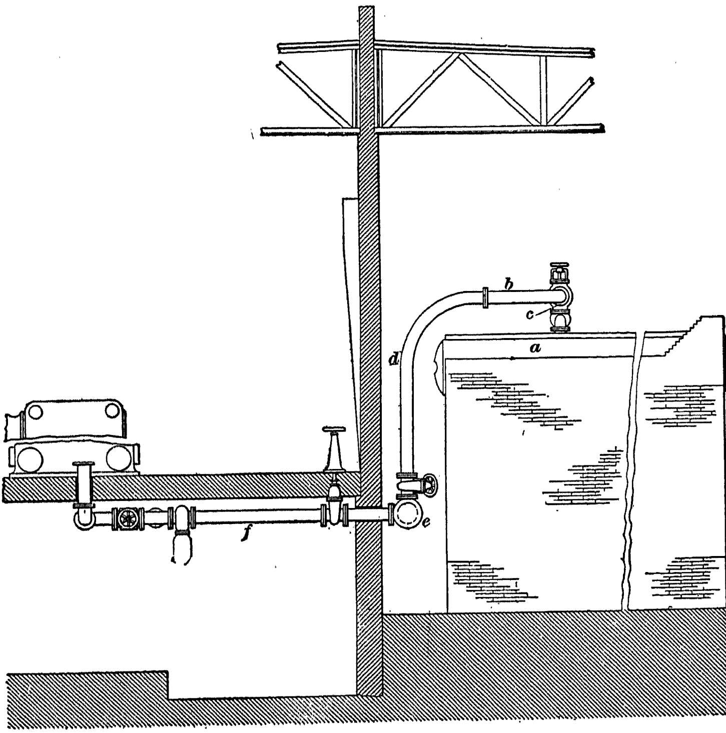


FIG. 55

header, and steam connections to engines below the engine-room floor are shown in Figs. 54 to 56. From the cross-connection between the steam drums *a* of the water-tube boilers leads a connection *b*, starting from an automatic stop- and check-valve *c*; the long-radius bend *b* is placed horizontally and connects with a similar bend *d* leading vertically downwards

to the live-steam header *e*. This arrangement gives great elasticity to a system of large piping, and the valves are in convenient positions for ready manipulation.

74. Only the main steam piping is shown in Figs. 54 to 56, the auxiliary piping for the boiler, feedwater heaters, etc. being omitted. Fig. 54 is a plan view, Fig. 55 an end view, and Fig. 56 a view showing the arrangement of the main steam pipes looking toward the rear of the boilers. The steam pipes *f*, running from the header *e* to the high-pressure cylinders of the steam engines, are placed under the engine-room floor, and a connection to the low-pressure cylinder is provided at *g*, so that in case of emergency the low-pressure cylinder can be run with high-pressure steam. By examining the arrangement of valves between the boilers and engines, it will be seen that without duplicate piping it is possible to cut out any engine or boiler in case of accident and still run the plant with the remaining engines and boilers. The main steam header is divided into two sections by the large gate valve *h*, Figs. 54 and 56, so that one half of the header can be cut off from the other half by closing the valve.

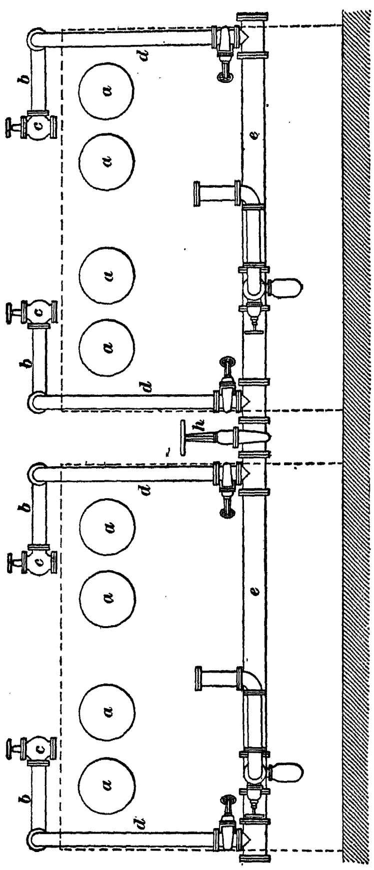
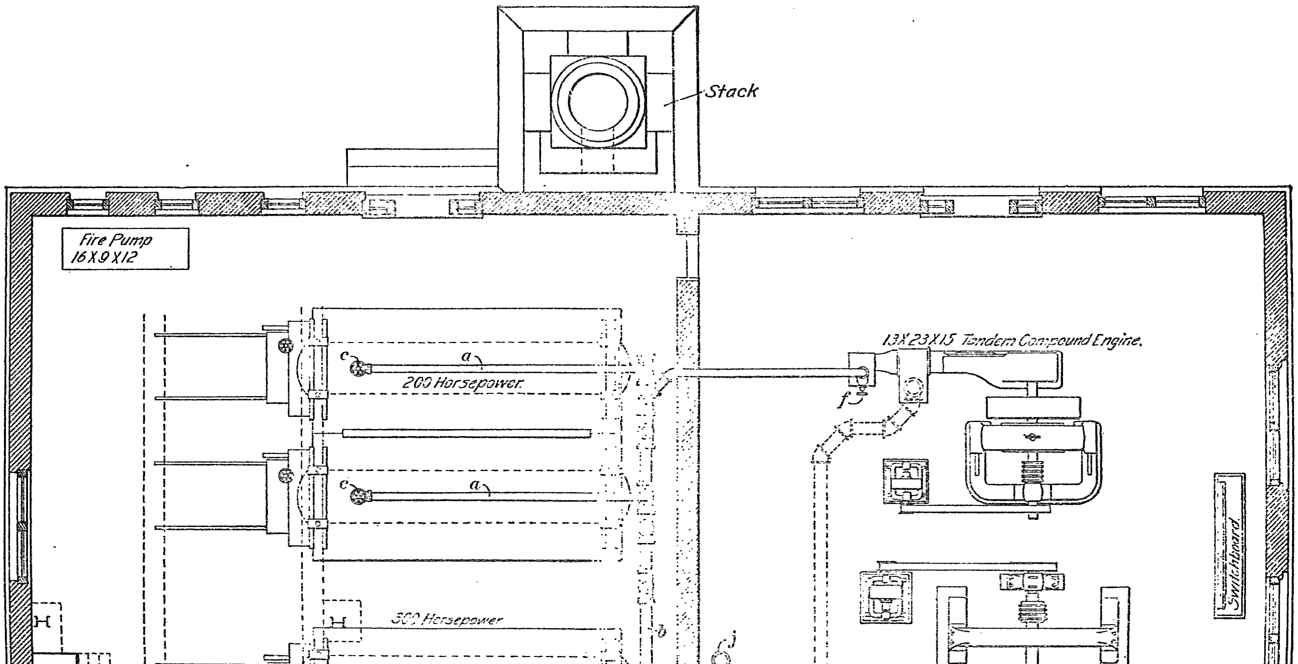
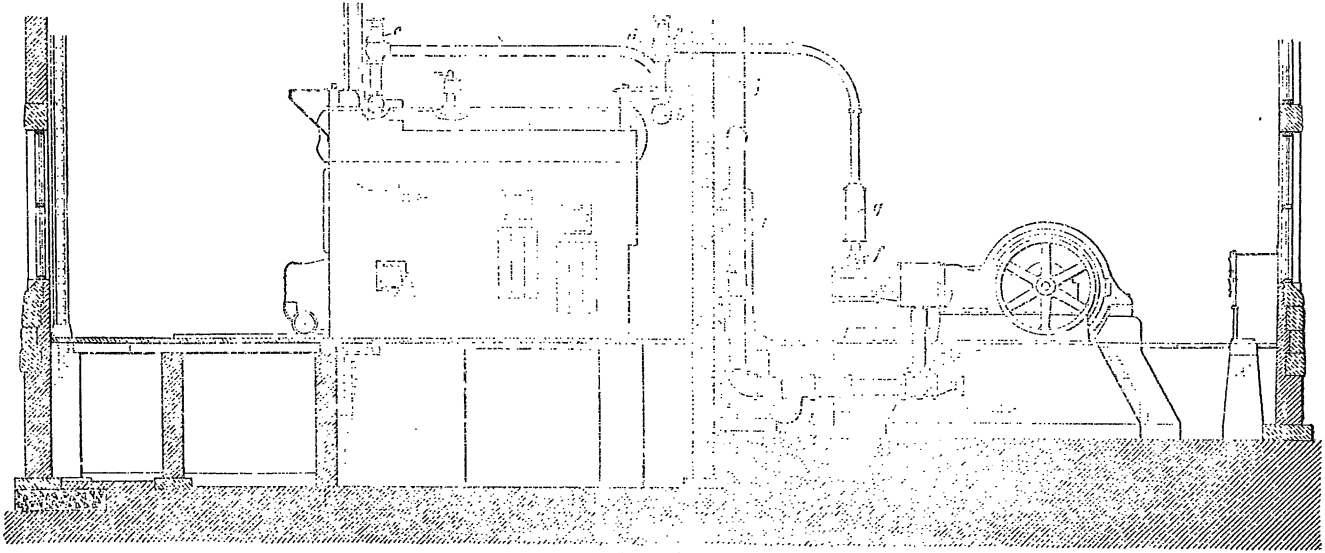


Fig. 56



Stack
Fire Pump
16 X 9 X 12
13 X 23 X 15 Tandem Compound Engine.
a
c
a
c
f
b
j
200 Horsepower.
300 Horsepower
Switchboard.

Plan View



Elevation

Fig. 57

I L T 459—2163

75. Steam Piping for Small Plant.—A plan and an elevation of the steam piping of a small electric-light plant are shown in Fig. 57. The station contains two 100-horsepower boilers and one 300-horsepower boiler, all of the water-tube type, which supply steam to two tandem-compound engines directly connected to electric generators. The branch steam pipes *a* from the three boilers deliver into a horizontal steam main *b* placed at the level of the drums, an angle stop-valve *c* being placed over each boiler, and each branch connecting to the top of the main with a long-radius bend *d*. The supply pipe for each engine is taken from the top of the main, each supply pipe being provided with an angle stop-valve *e* and a throttle valve *f* being placed close to the engine. A steam separator *g* is placed in each supply pipe directly over the throttle valve. Owing to the method in which the piping is run from the boilers to the engines, it is quite flexible, so that there will be little or no stress set up by its expansion or contraction.

76. The exhaust piping is shown by dotted lines in the plan view, Fig. 57. The exhaust pipes from the two engines are placed below the floor and are joined by means of a **Y** fitting *h* connecting with the main exhaust pipe, which conveys the exhaust steam through a closed feedwater heater *i* provided with a by-pass *j* to the atmosphere. A separator *k*, intended to remove oil from the exhaust steam before it reaches the heater, is placed in the main exhaust pipe.

The various pipe lines used for draining the piping, heaters, and separators, and the piping of the boiler feed-system, the fire-service pipes, the boiler blow-offs, and similar small piping found in a steam plant are not shown. The purpose of this illustration is chiefly to show the arrangement of the main steam pipes and valves.

SINGLE-PIPE AND DOUBLE-PIPE SYSTEMS

77. Single-Pipe System.—The diagrammatic view, Fig. 58, illustrates a general piping arrangement when a single-pipe system of piping is used to connect the boilers with the

prime movers, such as turbines or engines, or with pumps. The single-pipe system has a disadvantage in that a break in the main steam piping, although the piping is divided by valves, necessitates the closing down of a part of the plant until repairs can be made. However, if any of the boilers or prime movers are disabled, it is possible to place the unit out of commission for repairs by closing the valves in the piping leading to and from that unit. An auxiliary feedwater system should be installed to provide additional means for feeding water to the boilers in case the main feed supply is temporarily disabled. The single-pipe system is not suitable for very large power

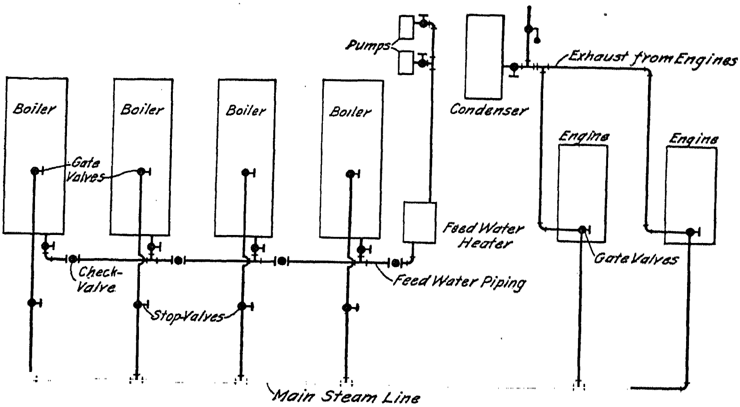


FIG. 58

plants, especially such plants as generate electricity for railways, lighting systems, and other purposes for which continuous service at full-load capacity is required.

78. Double-Pipe System.—The double-pipe system, or duplicate system, consists in connecting each boiler and prime mover with a double-pipe header and valves. The arrangement of piping and valves for such an installation is shown in Fig. 59. The cost of installation is greater than the single-pipe method, but this is offset by the greater reliability, as it insures continued service in the power plant. The main objection to the double-pipe system is that the colder pipes in the steam headers will be affected by the stresses arising from

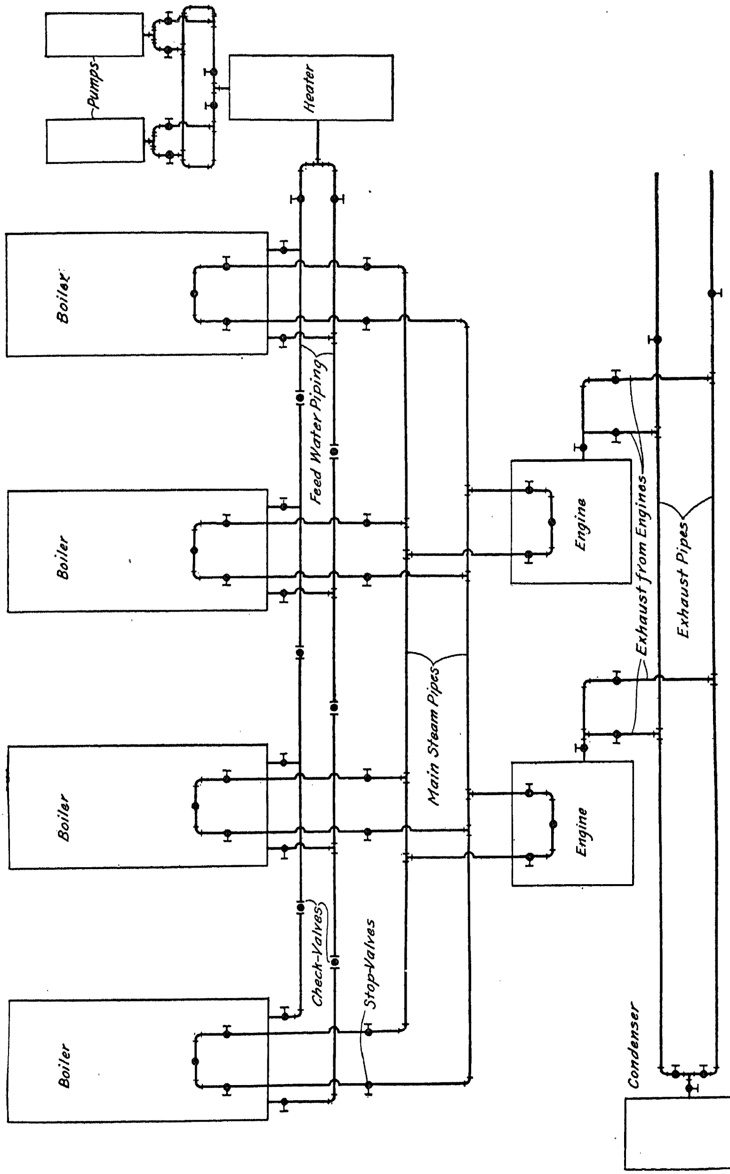

Pumps
Heater
Boiler
Boiler
Boiler
Boiler
Feed Water Piping
Main Steam Pipes
Check-Valves
Stop-Valves
Engine
Engine
Exhaust from Engines
Exhaust Pipes
Condenser

Fig. 59

the expansion of the active steam piping, thus causing conditions that are liable to produce leaky pipe joints. This trouble may be avoided by using long lines of piping and long-radius bends that will be sufficiently flexible to reduce the stresses on the pipe joints. Steam headers made in the form of loops are better adapted to take care of the expansion and contraction stresses. For large power plants, an auxiliary set of boilers and some prime mover units are included in the power equipment, thus involving an adequate piping system based on the principles applied in the double-pipe arrangement.

PIPE CALCULATIONS

STEAM-PIPE SIZES

79. Flow of Steam in Pipes.—Steam flows through a pipe because the pressure is higher at one end than at the other. The greater the difference of pressure at the ends, the faster will be the flow, and the greater will be the weight of steam delivered in a given time. The greater the velocity of flow of the steam, the smaller will be the diameter of the pipe for a given discharge of steam; thus, it is advantageous to have the steam travel rapidly, as the cost of pipe is reduced. Besides, a small pipe has less exposed surface than a large pipe, and so the heat loss from it will be less. On the other hand, the friction increases as the diameter of the pipe is reduced, and it increases as the square of the velocity; that is, if the velocity of flow of steam is made twice as great, the friction becomes about four times as great. The effect of this friction is to reduce the pressure at the discharge end, or to cause what is commonly called a drop of pressure. The drop of pressure increases at the same rate as the length of pipe increases, and is proportional to the weight per cubic foot of the steam, or the density of the steam. Thus, the problem of finding the size of steam pipe for a given service involves a compromise between a reasonable drop of pressure and as small a pipe as can feasibly be used.

80. There is a definite relation between the weight of steam delivered and the drop of pressure, which is given by the formula

$$W = C\sqrt{\frac{p\,w}{L}}$$

in which W = weight of steam flowing, in pounds per second;
C = a constant, the value of which depends on the pipe size;
p = drop of pressure, in pounds;
w = weight of steam, per cubic foot;
L = length of pipe, in feet.

The values of C for different pipe sizes are given in Table X.

The foregoing formula may be used to find the diameter of pipe for a given service by assuming a pipe diameter, finding the corresponding value of C from Table X, substituting in the formula, and finding the quantity W of steam discharged.

TABLE X

VALUES OF CONSTANT *C*

Nominal Size of Pipe Inches	Value of C	Nominal Size of Pipe Inches	Value of C
1	.75	6	97
$1\frac{1}{2}$	2.5	8	195
2	5.1	10	350
$2\frac{1}{2}$	8.5	12	550
3	15.5	14	800
4	32.5	16	1,100
5	60		

If the value is too small, or too large, another pipe size is assumed and the calculation is repeated. This is continued until a size is found that will give the desired capacity under the prescribed conditions.

EXAMPLE.—Find the size of pipe 160 feet long required to convey 2,800 pounds of saturated steam per hour, with a drop of pressure of 3 pounds, the pressure of the steam at the entrance to the pipe being 200 pounds per square inch, gauge.

SOLUTION.—A discharge of 2,800 lb. per hr. is equivalent to 2,800 $\div(60\times 60)=.78$ lb. per sec. This is the required capacity of the pipe. According to the example, $p=2$ lb. and $L=160$ ft. The weight of a cubic foot of saturated steam at 200 lb., gauge, or 215 lb., absolute, according to the Steam Table, is $w=.468$ lb. For a trial solution, assume a 2-in. pipe. The corresponding value of C, from Table X, is 5.1. Substitute these values in the formula, and

$$W=5.1\sqrt{\frac{3\times .468}{160}}=.48 \text{ lb. per sec.}$$

As the pipe must discharge at least .78 lb. per sec., it is plain that a 2-in. pipe is too small. So, try a $2\frac{1}{2}$-in. size, for which the value of C is 8.5, and again substitute in the formula. Then,

$$W=8.5\sqrt{\frac{3\times .468}{160}}=.8 \text{ lb. per sec.}$$

This is only slightly greater than the required discharge, and so a $2\frac{1}{2}$-in. pipe will be satisfactory. Ans.

81. Velocity of Steam in Pipes.—The pipe sizes used in connection with the transmission of saturated steam are such as to give steam velocities of from 3,500 to 6,000 feet per minute in the pipes. In the case of superheated steam, velocities of 12,000 feet per minute, or higher, are possible, because the weight of a cubic foot of superheated steam is less than that of a cubic foot of saturated steam at the same pressure. In reality, the velocity of flow is of no particular consequence, so long as the required capacity can be obtained without exceeding the allowable drop of pressure. The allowable drop of pressure may be from 1 to 5 pounds per 100 feet of length of pipe.

82. Supply Pipes for Steam Engines.—In the case of a pipe supplying steam to a turbine, the flow of steam is continuous; but if a reciprocating engine is used, steam flows into the engine cylinder during only a part of each stroke, so that the flow in the pipe is intermittent, rather than continuous. This point should be considered in calculating the size of a pipe to supply steam to a reciprocating engine. Suppose, for example, that an engine that cuts off at one-fourth stroke requires 3,600 pounds of steam per hour. As steam flows into the cylinder during only one-fourth of each stroke, the

3,600 pounds flows into the engine in $\frac{1}{4}$ hour, so that the rate of flow during the time the steam is in motion is $3{,}600 \div \frac{1}{4} = 14{,}400$ pounds per hour, or 4 pounds per second. Hence, in calculating the size of pipe for the engine, by the formula of Art. **80**, a capacity of $W = 4$ pounds per second must be obtained.

When the flow of steam in a steam pipe is continuous, as, for instance, in the supply pipe used for a turbine or a direct-acting steam pump, the weight of steam to be used for purposes of calculation is equal to the actual weight of steam used per second.

83. Sizes of Main Steam Pipes.—If a series of boilers A, B, C, and D are set in a battery and discharge into one main pipe, or header, the main pipe need not be of the same diameter throughout. Between boilers A and B it must be large enough to carry the steam from boiler A; between boilers B and C it must be large enough to carry the steam from boilers A and B; and so on. If all the boilers are of the same capacity, the calculations of the diameters of the sections is a simple matter. Suppose that the diameter of the main pipe between boilers A and B has been found to be d. Then, the diameter between boilers B and C must be $d\sqrt{2}$; between boilers C and D it must be $d\sqrt{3}$; and beyond boiler D, where it carries the discharge of all four boilers, it must be $d\sqrt{4} = 2\,d$.

84. Friction of Valves and Fittings.—An elbow or a valve in a steam pipe offers resistance to the flow and so increases the friction. In order that this friction may be taken into account in calculating the size of pipe required, it is customary to determine the length of straight pipe that would have the same frictional resistance as the valve or fitting. The value of L in the formula of Art. **80** is then taken as the sum of the actual length of pipe and the lengths of straight pipe having the same friction as the valves and fittings. The resistance at a globe valve is usually assumed to be about the same as that of a length of straight pipe equal to sixty times the pipe diameter, while the resistance at an

elbow is assumed to be approximately equal to two-thirds that of a globe valve. It is assumed that the resistance at the entrance to a pipe is equal to the resistance offered by a globe valve.

For example, suppose that a 3-inch pipe 128 feet long contains four elbows and three globe valves. Each globe valve has a resistance of $60\times3=180$ inches, or 15 feet, of straight 3-inch pipe. Each elbow has a resistance of $\frac{2}{3}\times15=10$ feet of 3-inch pipe. The resistance at the entrance is that of 15 feet of 3-inch pipe. Then, the equivalent length of pipe with which to make calculations is $L=128+15+(4\times10)+(3\times15)=228$ feet.

FLOW OF WATER IN PIPES

85. Finding Size of Pipe.—In power plants, piping is used to convey feedwater to boilers, cooling water to condensers, hot water to and from pumps, and so on. The determination of the size of pipe required to carry a known quantity of water, if it is to be made accurately, must take into account the length of the pipe, the number of bends, elbows, and valves, and the friction due to rubbing against the walls of the pipe at different velocities of flow. To consider the effect of these various factors, the calculations become intricate, and beyond the scope of this Section. However, it is possible to determine the approximate size of a pipe by simple general formulas. For example, if the quantity of water to be carried is stated in cubic feet per minute, the size of pipe may be found approximately by the formula

$$d=\sqrt{\frac{183\,Q}{v}} \qquad (1)$$

in which d = internal diameter of pipe, in inches;
Q = quantity of water, in cubic feet per minute;
v = average velocity of flow, in feet per minute.

If G denotes the number of gallons per minute, the formula becomes

$$d=\sqrt{\frac{24.4\,G}{v}} \qquad (2)$$

86. Velocity of Flow.—The average velocity v of the water in pipes in power plants ranges from 50 to 400 feet per minute, depending on the nature of the service. Suction lines to pumps should have low velocities of flow. Thus, a suction pipe for hot water should be based on a velocity of from 50 to 100 feet per minute, the lower values in the range being used for long pipes and pipes containing many bends and valves; if cold water is carried, the range may be from 100 to 200 feet per minute. In the case of feedpipes, the velocity may range from 200 to 400 feet per minute. The velocity in water-supply pipes to condensers may be from 300 to 400 feet per minute.

EXAMPLE 1.—A boiler requires 30,000 pounds of water per hour. What size of feedpipe is necessary, if the rate of flow is 360 feet per minute?

SOLUTION.—The amount of water required per minute is 30,000÷60 =500 lb. As water weighs 62.5 lb. per cu. ft., this is equivalent to 500÷62.5=8 cu. ft. per min. Apply formula **1**, Art. **85**, making Q=8 cu. ft. and v=360 ft. per min.; then,

$$d=\sqrt{\frac{183\times 8}{360}}=2 \text{ in.}$$

Therefore, an extra-heavy 2-in. pipe may be used although a $2\frac{1}{2}$-in. pipe would be better. Ans.

EXAMPLE 2.—Find the size of pipe required to convey 264 gallons of water per minute to a condenser, if the average velocity of flow is 400 feet per minute.

SOLUTION.—Apply formula **2**, Art. **85**, making G=264 gal. per min. and v=400 ft. per min.; then,

$$d=\sqrt{\frac{24.4\times 264}{400}}=4.01 \text{ in.}$$

Therefore, a standard 4-in. pipe would be used. Ans.

BOILER FURNACES, SETTINGS, AND CHIMNEYS

(PART 1)

FURNACES OF STEAM BOILERS

FURNACE DESIGN AND CONSTRUCTION

CONDITIONS AFFECTING FURNACE DESIGN

1. Furnace Volume.—To insure economical operation of a steam boiler, the height, width, and length of the furnace must be such as to enable the gases to be burned completely before they are brought in contact with the heating surfaces. The relative proportions of the furnace therefore depend on the kind and quality of fuel used and the location of the heating surfaces. For example, a short, wide furnace having a small volume is not suitable for burning fuel that contains a large percentage of volatile matter; a long, narrow furnace is preferable to a short, wide one of the same volume. To prevent contact of the gases with the boiler surfaces until combustion is completed, walls and arches are used. These are faced or lined with refractory brick having great heat-resisting qualities. The linings absorb heat, help to maintain a high uniform temperature in the furnace, and promote combustion.

2. If the boiler is internally fired, of the locomotive type or the vertical type, the crown sheet should be as far as possible above the grate, so as to give a large furnace volume and

prevent the hot gases from striking the crown sheet and being cooled before combustion is completed. The temperature at which ignition of the volatile gases can take place is from about 900° to 1,200° F.; therefore, if unconsumed gases are brought in contact with plates having a temperature of from 350° to 400° F., they will be cooled below the ignition point, and if they are not subsequently brought to a temperature at which they will burn, they will pass out to the stack and the heat value of the fuel they contain will be wasted. This explains why a high furnace temperature, aided by incandescent walls of refractory brick, is valuable in promoting combustion and preventing fuel loss.

3. Furnace Temperature.—If the furnace is external to the boiler, and is bounded by firebrick walls, the furnace temperature may be as high as 2,500° or 3,000° F.; but if the furnace is internal, and surrounded by water-cooled plates, the temperature rarely rises above 2,000° F. A high temperature is desirable, for the reason already stated; and an additional reason is that the transfer of heat from the gases to the water is more rapid with a high than with a low furnace temperature. To insure complete combustion of the fuel gases, an excess of air above that theoretically required is always supplied to the furnace. At ordinary rates of combustion, the excess ranges from 25 to 50 per cent.; but when the fires are forced, the excess may be from 100 to 300 per cent. This air enters the furnace at a temperature of from 50° to 90° F. and escapes to the chimney at a temperature of from 400° to 600° F.; thus, air supplied beyond that needed for combustion reduces the furnace temperature and causes loss by carrying away heat.

4. Effect of Composition of Coal on Furnace Volume. Coal having a high percentage of volatile matter, such as bituminous coal, which burns with a long, smoky flame, requires a much larger combustion space than coal of low volatile content. Hence, the volume of the furnace is governed by the quantity and nature of the volatile matter in the fuel and the rate at which the fuel is burned. The Bureau of Mines has conducted experiments with bituminous coals of three grades

—Pocahontas, Pittsburgh, and Illinois—having, respectively, 13, 35, and 47 per cent. of volatile matter. The results are given in Table I. In the first column is shown the degree of completeness of combustion attained by stating the percentage of the heat undeveloped, and in the second and third columns are shown the varying conditions of excess air and rate of burning of the coal. In the last three columns is shown how many cubic feet of combustion space are required for each grade of coal under the conditions stated in the first three columns. It is seen at once that the coal with the greatest percentage of volatile matter requires the largest volume of furnace.

5. The values in Table I bring out several other interesting facts. In the case of any one of the grades of coal tested, the loss due to undeveloped heat is lowered by increasing the

TABLE I

SIZE OF COMBUSTION SPACE FOR BITUMINOUS COALS

Undeveloped Heat Per Cent.	Rate of Combustion Pounds per Square Foot of Grate per Hour	Excess Air Per Cent.	Combustion Space Cubic Feet per Square Foot of Grate Area		
			Pocahontas Coal	Pittsburgh Coal	Illinois Coal
5	50	50	2.7	2.9	4.3
3	50	50	3.2	3.7	5.3
2	50	50	3.6	4.4	6.3
1	50	50	4.0	5.6	8.9
.5	50	50	4.8	6.8	11.9
5	25	50	2.0	2.2	3.5
3	25	50	2.3	2.7	4.35
2	25	50	2.7	3.1	5.1
1	25	50	3.4	4.0	6.2
.5	25	50	4.0	5.0	7.1

furnace volume, showing that the combustion became more nearly complete as the space provided for mixing and burning the gases was increased. The size of combustion space

required does not vary in direct proportion to the quantity of volatile matter. For instance, doubling the rate at which the fuel is burned doubles the amount of volatile matter driven off from the coal in a given time; but it will be seen from the table that the combustion space is not doubled. For example, take Pittsburgh coal with a loss of 3 per cent. in undeveloped heat. At a rate of firing of 25 pounds of coal per square foot of grate, the furnace volume is 2.7 cubic feet per square foot of grate, whereas, at 50 pounds per square foot it is 3.7 cubic feet, or only about 37 per cent. larger; that is, doubling the rate of fuel consumption required an increase of only about 37 per cent. in furnace volume.

6. Firebrick Arches and Walls.—In locomotive boilers that burn bituminous coal, arches built over the fuel bed assist in promoting combustion. The arches are built of firebrick blocks and are supported by arch tubes. The firebricks become incandescent and thus tend to maintain a uniform temperature in the furnace. At the same time, the arch lengthens the travel of the hot gases and prevents cool air from striking the tube-sheet and firebox plates. The same principle may be adapted to other types of boilers. For example, the Scotch boiler or the Clyde boiler has furnace flues of large diameter opening into combustion chambers. The combustion chambers opposite the ends of the flues may profitably have firebrick linings; for, after the brick becomes heated, any unconsumed gases leaving the flue will be ignited by the incandescent brickwork and thus will be prevented from escaping to the stack unburned. Externally fired boilers have various arrangements of brickwork and baffles to prevent the escape of unconsumed furnace gases.

7. Distance Between Boiler and Grate.—If the setting of a water-tube boiler is such that the gases rising vertically from the fuel on the grates immediately come in contact with the tubes, they are chilled and the process of combustion is checked before they have become thoroughly mixed with air. To prevent this condition, it is advisable to set the boiler so that the tubes are well above the grates, thus providing a combus-

tion chamber of considerable volume. The addition of a fire-brick arch over the fire may also prove advantageous The percentage of volatile matter contained by the fuel governs the distance from the grate to the lowest row of tubes. For burning anthracite, the minimum distance is ordinarily about 40 inches, as the flame is short and there is little volatile matter. For burning bituminous coal, the distance should be 60 inches or more.

8. In the setting of horizontal return-tubular boilers, the Hartford Steam Boiler Insurance Company recommends certain distances from the grates to the boiler shell and from

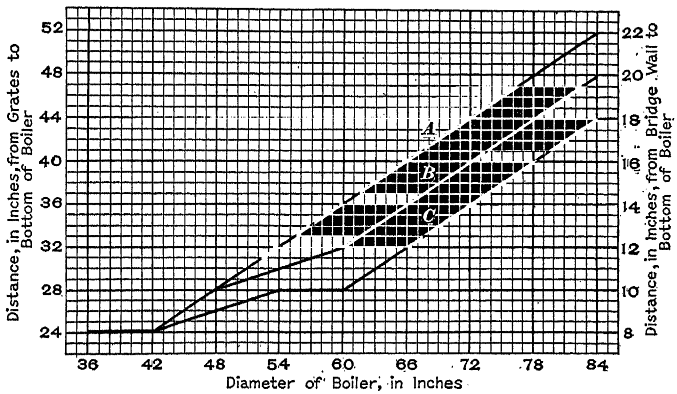


FIG. 1

the top of the bridge wall to the shell, for different kinds of fuel. This information has been condensed into the form of a diagram, as shown in Fig. 1. The method of using the diagram is to locate the diameter of the boiler along the base line and from this point to follow vertically to the diagonal line corresponding to the fuel used. From the intersection on the diagonal, proceed horizontally to the left, and the scale at the left will show the distance between the grates and the shell; proceed to the right from the same point on the diagonal, and the right-hand scale will show the distance between the top of the bridge wall and the shell. The diagonal *A* is to be used if the fuel is bituminous coal having more than 35 per cent. of

volatile matter, as Illinois coal; the diagonal *B* is for bituminous coal having from 18 to 35 per cent. of volatile matter, as Pittsburgh coals; and the diagonal *C* is for semi-anthracite and anthracite containing less than 18 per cent. of volatile matter, as Pocahontas and Georges Creek coals.

EXAMPLE.—A return-tubular boiler 72 inches in diameter is to be fired with bituminous coal containing 27 per cent. of volatile matter. Find (*a*) the distance from the grates to the shell and (*b*) the distance from the bridge wall to the shell.

SOLUTION.—(*a*) As the fuel contains 27 per cent. of volatile matter, the diagonal *B*, Fig. 1, must be used. At the bottom of the diagram locate 72 and proceed vertically to the line *B*. From this point proceed horizontally to the scale at the left, where 40 inches is indicated. This is then the height of the boiler shell above the grates. Ans.

(*b*) From the same point on the diagonal *B* proceed horizontally to the scale at the right, where 16 inches is indicated. This is the distance between the shell and the top of the bridge wall. Ans.

FURNACE AND ASH-PIT DETAILS

9. Furnace Mouth.—The fronts of boilers consist of steel or cast iron, lined with firebrick to prevent their warping and burning under the action of heat from the furnace. They contain the openings to the furnace and the ash-pit. The fire-door opening should be flared outwards on the side toward the furnace, as shown in the sectional view, Fig. 2, so that any part of the furnace may be reached easily by the firing tools.

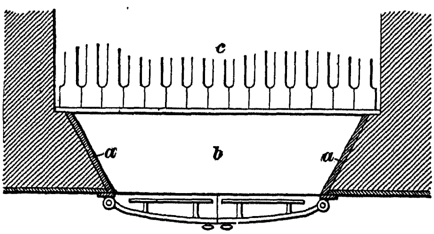


FIG. 2

The sides and front wall of the furnace are indicated by cross-section lines. The furnace mouth, or fire-door opening, is fitted with cast-iron cheek plates *a* at the sides, and a dead plate *b* forms the bottom of the opening and serves as a support for the front ends of the grate bars *c*; also, fresh fuel is thrown on the dead plate and allowed to remain until

the volatile matter is driven off, after which it is pushed back on the grates. A dead plate is shown in Fig. 3. The offset lip *a* supports the ends of the grate bars and the flat

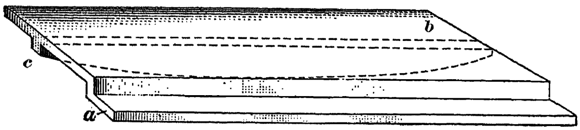


FIG. 3

part *b* forms the floor of the furnace mouth. A heavy rib *c* strengthens the plate against warping and cracking.

10. The top of the furnace mouth may be protected by an arch constructed as shown in Fig. 4. A cast-iron arch plate *a* is built into the brickwork of the furnace front and forms a support for special firebricks *b* that are dovetailed and held in dovetails in the under side of the arch plate. These bricks may readily be removed when burned out, and be replaced by new ones. Some engineers prefer a water-cooled arch, as shown in Fig. 5. By this construction, horizontal pipes *a* form the top of the furnace mouth. These pipes are connected to headers *b* that communicate with the boiler at different levels through the pipes *c* and *d*. The water in the pipes *a*

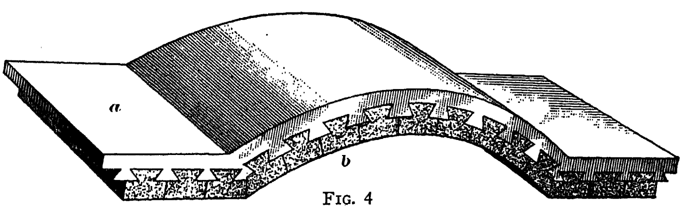


FIG. 4

becomes heated and a circulation is set up in the pipes, thus preventing them from being burned out. Firebrick is laid on top of the pipes to form the top of the arch, and thus a water-cooled arch is obtained. Mud and sediment may be blown out of the pipes and headers by opening the valve *e*.

11. Intense heat is generated near the fire-doors, and unless protective devices are used it will be necessary, frequently, to

renew the door linings, arches, side walls, and dead plates. One method of arranging water pipes for protection has been described. Another method of accomplishing the same purpose is shown in Fig. 6 (*a*) and (*b*). Two rings *a* of half-oval section, as shown at *b*, are connected by the pipes *c* and *d*. Connection is made with the water space of the boiler by the pipes *e* and *f*, so that the hollow rings are filled with water when

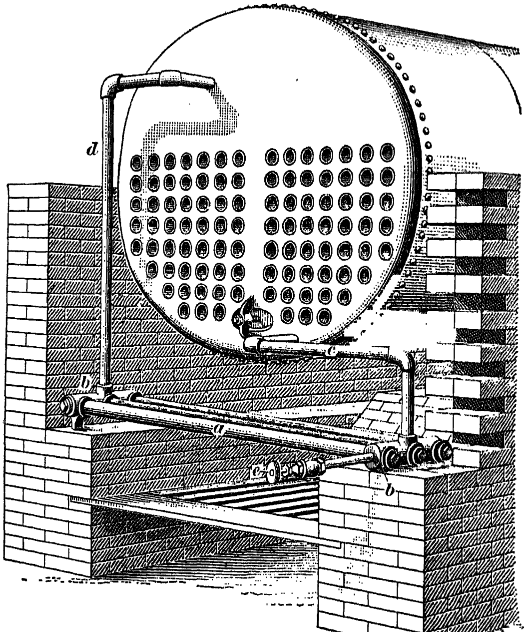


FIG. 5

the boiler is in operation. The rings are set in the boiler front and form the sides and arched tops of the fire-door openings. As the level *g h* of the top of the grates is above the bottom inside surface of the ring, a dead plate *i* is inserted. Blow-off connections *j* allow the rings and pipes to be cleaned of sediment.

12. Bridge Wall.—The bridge wall is a low wall built across from one side wall of the setting to the other, beneath

the boiler shell. It forms the rear wall of the furnace and acts as a support for the rear ends of the grate bars. It is usually built of common brick, but is faced with fire-brick on the side toward the furnace. At the side facing the rear of the boiler the wall should be vertical. The top of the bridge wall should

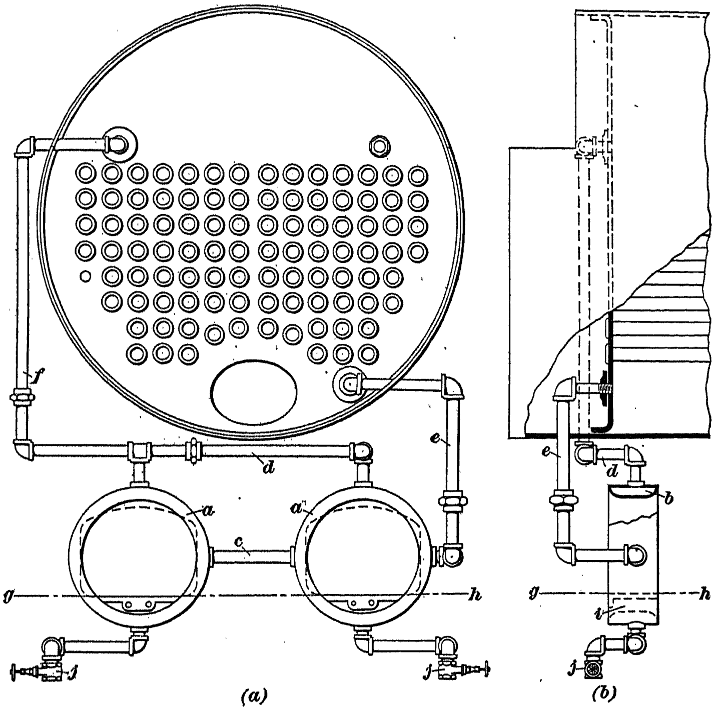


FIG. 6

be horizontal; that is, it should not be curved to conform to the shape of the boiler shell. The bridge wall deflects the hot gases upwards and brings them in close contact with the boiler shell; also, because of its becoming highly heated, it aids in the combustion of the fuel, especially when bituminous coal is used.

13. Rear Arch.—At the back end of the setting of a return-tubular boiler, above the upper row of tubes, an arch must be

built to deflect the hot gases from the combustion space into the tubes. It must extend from one side wall to the other and must be so constructed that it will not break under repeated expansion and contraction. It may be either curved or flat. An example of flat arch is shown in Fig. 7. Angle-iron supports *a* extend from one side wall to the other and from them are hung a number of circular iron plates *b* by bolts *c*. The slab *b* that forms the arch is composed of refractory material that is prepared in plastic form and pressed into place over and around the plates *b* and bolts *c*, between the side walls and between the boiler and the rear wall *e*, after which it is allowed to dry and harden. By this construction, none of the metal in the supporting frame is exposed to the direct action of hot gases. The arch must be above the tubes, so that they are accessible at the rear for repairs; also, the joints between it and the

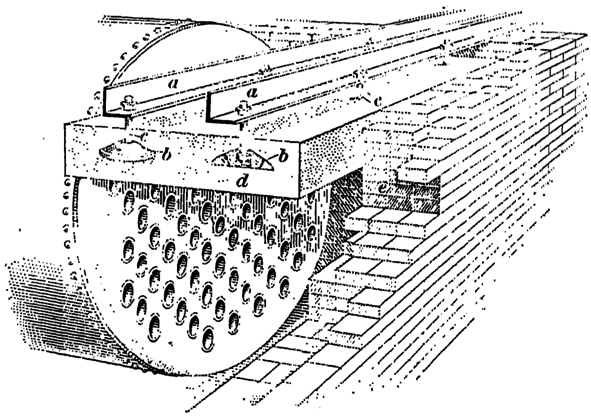
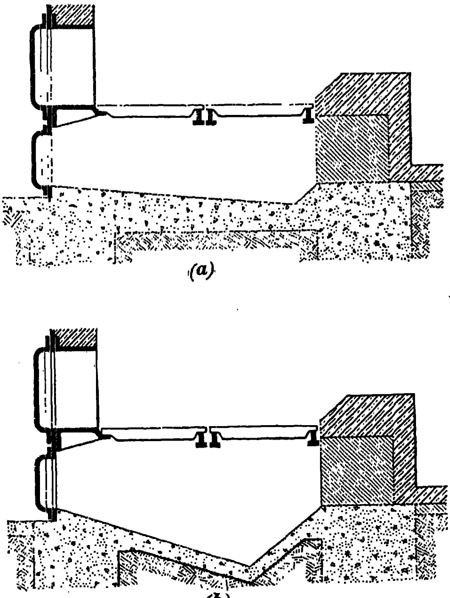


FIG. 7

walls must be tight, to prevent leakage of air into the setting, with consequent lowering of temperature of the hot gases. Asbestos rope may be used to plug up all crevices.

14. Ash-Pits.—The space below the grates of an externally fired boiler forms the ash-pit, which may be walled with brick or concrete. The size and shape of the ash-pit depend on the size of the boiler, the type of furnace and grates, and the

quality of the coal burned. The capacity should be such as to take care of the ashes for a working period of from 16 to 20 hours for hand-fired boilers, and from 12 to 16 hours for stoker-fired boilers, so that too frequent cleaning of the ash-pit may be avoided. As a cubic foot of ashes weighs approximately 40 pounds, the size of ash-pit may be determined by using the following rule:


(a)

(b)

FIG. 8

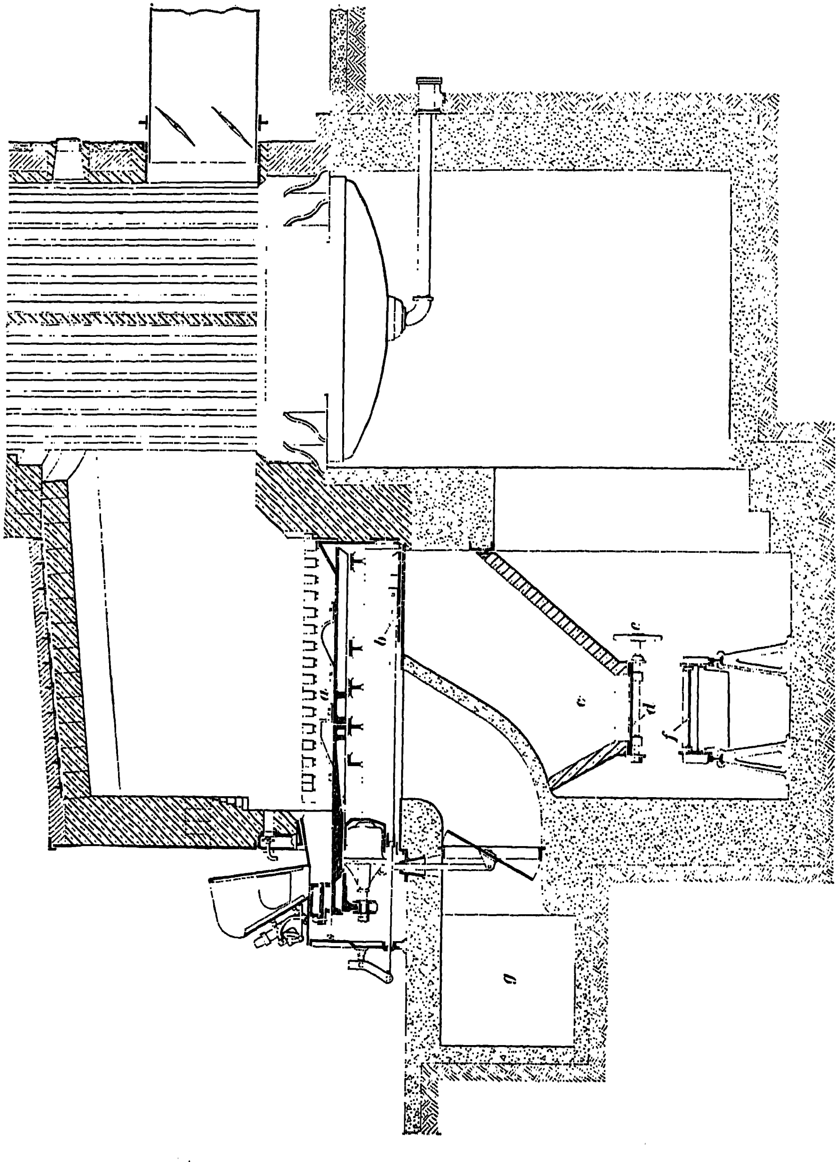
Rule.—*To find the volume of ashes per hour, in cubic feet, multiply together the grate area, in square feet, the number of pounds of coal burned per hour per square foot of grate area, and the percentage of ash in the coal, expressed as a decimal, and divide the product by 40.*

Expressed as a formula, this rule becomes

$$V = \frac{AWC}{40}$$

in which V = volume of ashes per hour, in cubic feet;
A = grate area, in square feet;
W = pounds of coal burned per hour per square foot of grate area;
C = percentage of ash in coal, expressed as a decimal.

EXAMPLE.—A boiler having a grate area of 50 square feet burns 24 pounds of coal per hour per square foot of grate. If the coal contains $22\frac{1}{2}$ per cent. of ash, what ash-pit volume is required for a working period of 18 hours?


a
b
c
d
e
f
g

Solution.—Use the formula, and make $A=50$ sq. ft., $W=24$ lb., and $C=.225$; then,

$$V=\frac{50\times24\times.225}{40}=6.75 \text{ cu. ft. per hr.}$$

For 18 hr. of working, the volume required will be $18\times6.75=121\frac{1}{2}$ cu. ft. Ans.

15. The method of removing the ashes, whether by hand or by mechanical means, must also be considered in the design of the ash-pit. The pit should be so arranged that it will be accessible for cleaning and so that ample room will be given for the use of the cleaning hoe and the shovel. Examples of ash-pit arrangement are shown in Fig. 8. That shown in (*a*) is a simple form for a hand-fired furnace. If greater volume is required, it may be obtained by constructing the pit as in (*b*). The ashes from furnaces fitted with mechanical stokers may be removed by hand, but it is common to remove them by some sort of conveyer. The ash-pit construction shown in Fig. 9 is of the latter class. The ashes produced by combustion are pushed off at the rear end of the stoker *a* and fall on a gate *b* that, when opened, allows them to fall into the ash hopper *c*. A gate *d* controlled by the hand wheel *e* may be opened to discharge the ashes into the buckets of a conveyer *f*, by which they are removed. The passage *g* is a duct that supplies air beneath the stoker.

SPECIAL TYPES OF FURNACES

16. Dutch Oven.—The Dutch-oven type of furnace, as illustrated in Fig. 10, consists of a brick chamber that encloses the furnace on the sides, top, and front. It is not located beneath the boiler, but is set at the front of the boiler, as shown, thus removing the burning fuel to a great distance from the heating surfaces. It is especially valuable for burning light fuels, such as sawdust, shavings, and other wood refuse, these usually being fed into hoppers fitted to openings directly above the grates, in the top of the oven; however, the fuel may be fed through the fire-door in the front. This type of furnace provides a large grate area, a combustion chamber of large volume, and, because of its position relative to the boiler,

a longer travel of the hot gases than is the case in the ordinary boiler setting. The firebrick walls surrounding the furnace maintain a more nearly uniform temperature and promote combustion of the gases.

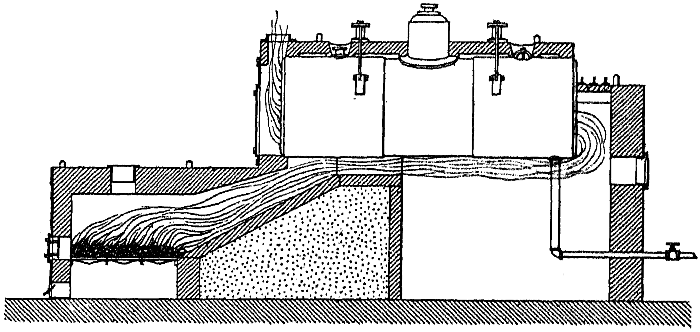


FIG. 10

17. Hawley Down-Draft Furnace.—The Hawley down-draft furnace, an example of which is illustrated in Fig. 11, is so called because the draft through one of the two sets of grates used is downwards instead of upwards. The upper

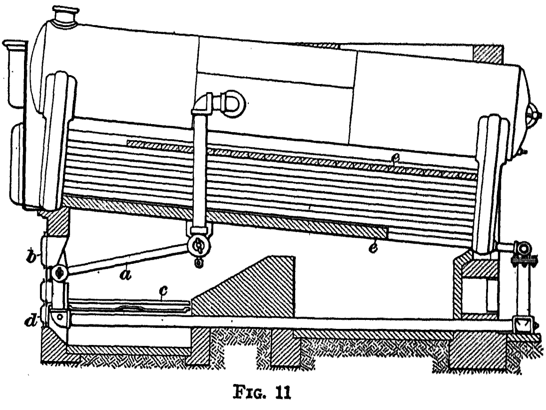


FIG. 11

grate *a* is a water grate; that is, it consists of pipes expanded into headers at their ends, the headers being connected to the water space of the boiler to insure continuous circulation of water. Fresh fuel is thrown on the grate *a* through the fire-

door *b* and air for its combustion is admitted above the grate. After the volatile matter has been burned away, the partly burned fuel falls to the lower grates *c*, where combustion is completed, the air supply being admitted through the door *d* below this grate in the usual way. The distance between the grates *a* and *c* ranges from about 12 inches at the front to 18 inches at the rear. Baffles *e* are arranged to give the hot gases a long travel over the heating surfaces of the boiler.

18. A view of the water grate used in the Hawley down-draft furnace is shown in Fig. 12. The pipes *a* are rather widely

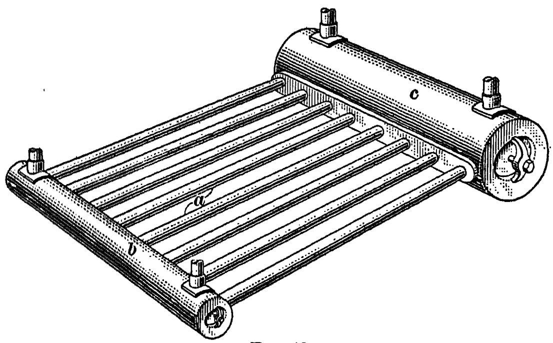


FIG. 12

spaced and the ends of the drums, or headers, *b* and *c* are provided with handholes so that cleaning may readily be done. The relative positions of the upper and lower grates, Fig. 11, are such that the volatile matter driven off from the first fuel on the upper grate is forced to pass down into the furnace space above the lower grate. The consequence is that there is greater likelihood that the combustible gases will be thoroughly consumed than if the fuel were fired directly on the lower grate.

The Hawley furnace is a successful smoke-prevention device and the makers claim that it will burn low-grade fuels with a high efficiency. It is not automatic in its action and is therefore not so well adapted to the saving of labor in the fireroom nor for use with coal-handling machinery as most automatic stokers; this, however, is not a serious objection in small plants.

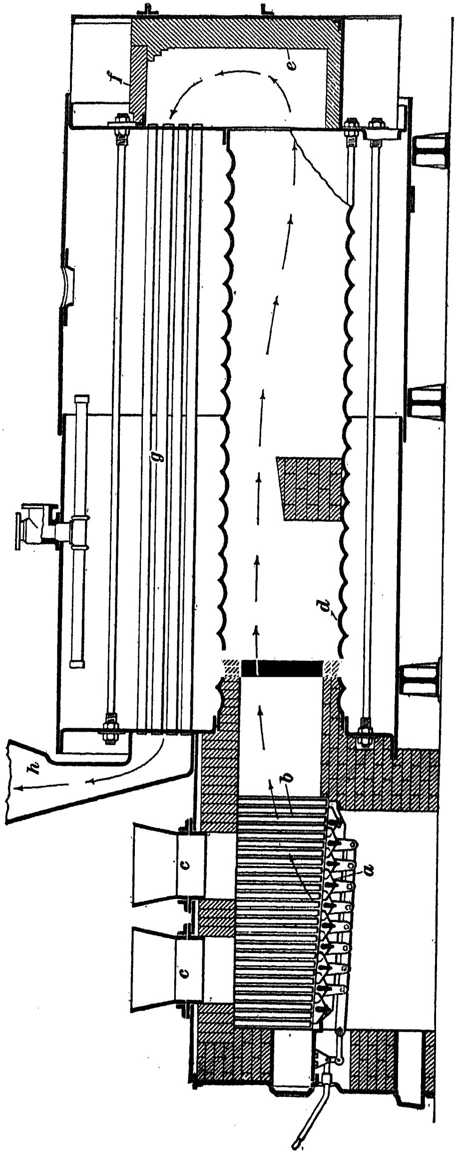


FIG. 13

19. Burke Furnace.—The details of the Burke furnace and setting for a corrugated-flue boiler are illustrated in Fig. 13. The furnace, like the Dutch oven, extends outside the boiler setting and uses a set of shaking grates *a* in connection with fixed or stationary grates *b*. The stationary grates, which are at the sides of the furnace, slope toward the rocking grates, and have such a pitch that the coal will slide down by gravity at such a rate that it will be coked by the time it reaches the shaking grates. The coal is fired through the hoppers *c* at the

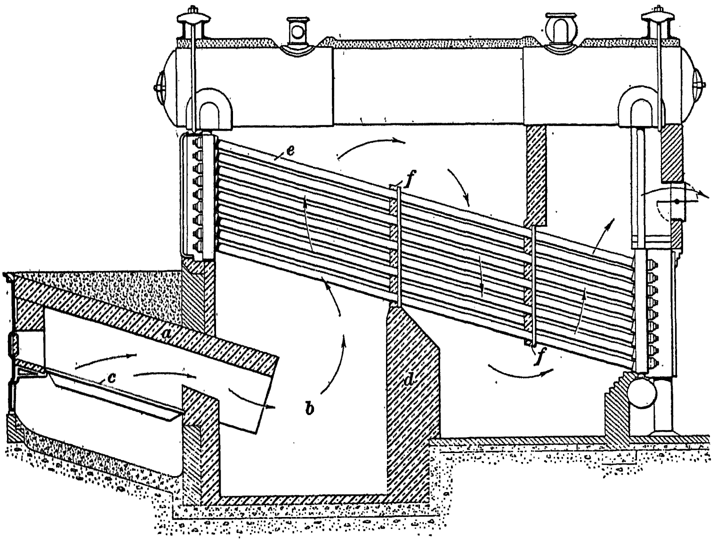


FIG. 14

sides, and the firing is controlled by hand, which makes this form of furnace practically a hand-fired stoker. The hot gases from the furnace pass through the corrugated furnace flue *d* back against the firebrick wall *e* and the combustion chamber arch *f*, through the tubes *g* and thence to the breeching *h*.

20. Dorrance Furnace.—The Dorrance furnace, shown in Fig. 14, is another modification of the Dutch oven. The sloping firebrick arch *a* is inclined toward the rear of the furnace and extends into the combustion chamber *b*, the grates *c*

being parallel with the arch *a*. Back of the arch *a* is built a brick pier *d* against which the gases strike and are deflected back upon themselves, thus insuring a more thorough mixing of the gases and air. The water-tubes *e* are baffled at *f* to give the gases a longer travel. By this form of furnace construction a high furnace temperature is obtained, owing to the intimate mixing of the gases and air and their combustion before they strike the cooler boiler surfaces.

21. Wooley Furnace.—The Wooley furnace and setting for a water-tube boiler are illustrated in Fig. 15. The furnace *a* is practically a Dutch oven and is so constructed as to

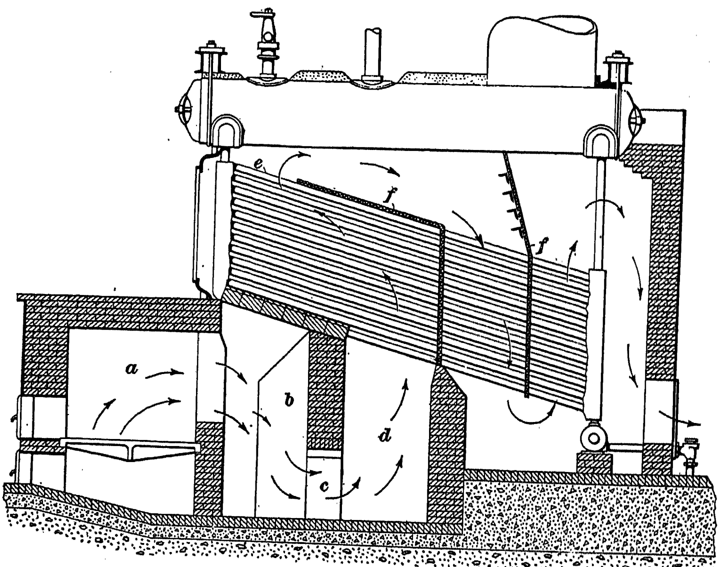


FIG. 15

provide a very large grate area and combustion chamber. A brick wall *b* is built up solid except at the bottom, where arched openings *c* are provided. A view of the wall is shown in Fig. 16, as it appears from the front of the furnace. Fire-bricks are used for facing the wall *b*, and as these bricks withstand and maintain high temperatures, the wall promotes combustion. By placing the gas openings *c* at the bottom of

the wall, the gases must travel downwards into a second combustion chamber *d*, Fig. 15, before striking the tubes *e*. Considerable heat is absorbed by the brick walls and floor; but after they are thoroughly heated they assist in maintaining efficient combustion. Baffles *f* are used to increase the gas travel around the tubes.

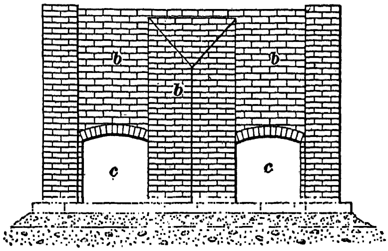


FIG. 16

GRATES

STATIONARY GRATES

22. Grate Characteristics.—Grates are generally made of cast iron, which is the material best suited to withstand heat and form a support for the fuel to be burned. Air spaces must be provided between the bar sections or in the bars for the admission of air under the bed of fuel. Authorities differ as to the proper width of air space; in general, it should be made as great as possible and still prevent the fuel from dropping through. For the larger sizes of anthracite, such as egg and nut, and for bituminous and coking fuels, the air space may be made from $\frac{5}{8}$ to $\frac{3}{4}$ inch in width; for pea coal, from $\frac{3}{8}$ to $\frac{1}{2}$ inch; for fine coal, such as buckwheat, rice, culm, and slack, an air space from $\frac{3}{16}$ to $\frac{3}{8}$ inch in width may be used. The air spaces are distributed uniformly over the grate surface so as to avoid blowing holes in the fuel bed. The area of the solid portion of the grate is usually made somewhat greater than the combined area of the air spaces. Grates are divided into two classes: *fixed* or *stationary grates* and *shaking grates*.

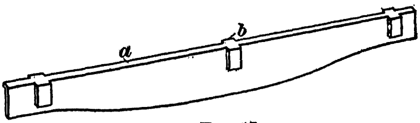


FIG. 17

23. Common Form of Fixed Grate.—The most common type of fixed grate is made of straight single bars *a*, Fig. 17, placed side by side in the furnace. The thickness of the bar

section depends on the width of the grate, on the air space, and on the number of bar sections in each grate bar. It is the general practice to make the thickness across the lugs *b* twice the thickness of the bar *a*. The depth of the bar is made about 2 inches at the ends and ranges from 3 to 5 inches at the center.

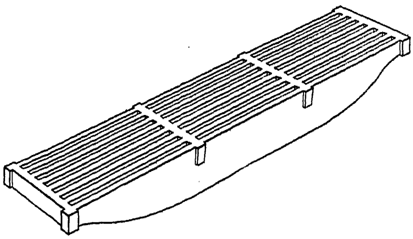


FIG. 18

For long furnaces the bars are made in sections 3 feet in length, and a bearer bar is placed in the center of the furnace to support the grate bars. Long grates are set with a downward slope toward the bridge wall of about $\frac{3}{4}$ inch per foot of length. This position facilitates the admission of air at the rear of the grate, and also the cleaning of the grate.

Grate bars are also made in sections having two or more bars united in a single casting, as shown in Fig. 18. Bars of this kind range in width from 3 to 6 inches and are stronger than the single-bar units. They have the disadvantage, however, that in case of breakage or warping, it costs more to replace them than to replace single bars. Another disadvantage is that the bars must be so thin, in proportion to their length, that they will warp out of shape, and consequently break, especially under forced firing.

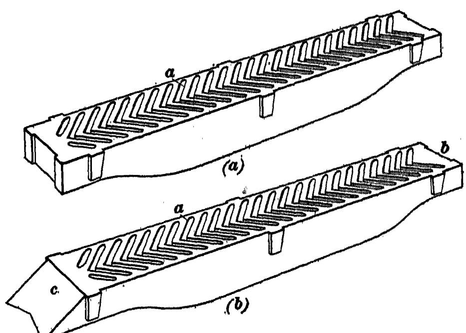


FIG. 19

24. The *herring-bone grate bar*, shown in Fig. 19 (*a*) and (*b*), can expand and contract freely, owing to the angular shape of the cross-bars *a*, and for this reason it is superseding the ordinary straight type. Herring-bone bars are made in various

forms and widths of air spaces. The grate bar is made with straight ends, as in (*a*), when used for grates in which two lengths are required. The bar shown in (*b*) has one straight end *b* and the other end *c* beveled. The end *c* is set against the bridge wall and the bevel prevents ashes from crowding between the grate and the wall; thus the grate bar is free to expand without danger of damaging the grate or the setting.

25. Sawdust Grate.—A form of cast-iron grate bar especially adapted to burning sawdust is shown in Fig. 20.

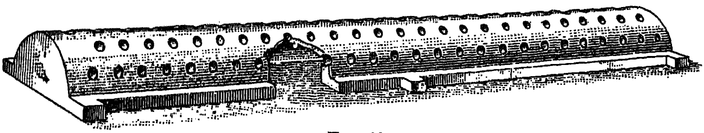


FIG. 20

The bar is semicircular in cross-section and is provided with circular openings for the introduction of air. As in other types, lugs are cast on each side of the bar to serve as distance pieces and maintain air spaces between the bars.

26. Special Forms of Grate Bars.—Wrought-iron grate bars are rolled from a single bar; they have a head and a web and are uniform in depth. They are made up in sets and riveted together, with distance pieces between the bars to form the required air space. Hollow grate bars through which water circulates are sometimes used.

27. Adapting Grate to Fuel.—In general, a grate bar should be especially suited for the kind of fuel to be burned. Thus, if very fine coal is to be burned, a grate bar like that shown in Fig. 21, having small air spaces, should be used, since otherwise a large percentage of the fuel will fall into the ash-pit. On the other hand, for the large sizes of coal it is advisable to provide bars having large air spaces, using the largest air

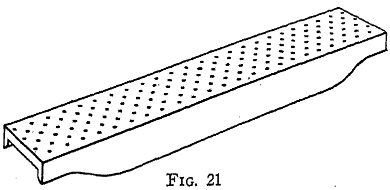


FIG. 21

space when caking coals are to be burned. Some varieties of bituminous coal will cake, that is, fuse together to a considerable degree, and the ashes and clinkers formed are of such size that a large part of them cannot pass through the air spaces unless these are large; the grate thus becomes clogged, shutting off the air from the fire, which reduces the rate of combustion and evaporation.

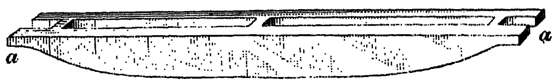


FIG. 22

28. Installing Stationary Grate Bars.—Grate bars must be installed in such a manner that they can expand freely and without damage to the boiler setting. The front ends of the grate bars are supported on the dead plate, and the rear ends are usually supported by the bridge wall. The space between the ends of the grate bars and their support will fill up with cinders and ashes, which will become hard and prevent the bars from expanding freely if this refuse is not removed frequently. To overcome this trouble, the grate bars may be supported by *bearer bars*, one form of which is shown in Fig. 22. The ends *a* of the bearer bars are set into the side walls of the furnace and the ends of the grate bars rest on the bearer bars; but a better construction is to set a cast-iron box *a*, Fig. 23, directly in the brick side walls and then place the bearer bars *b* so that the

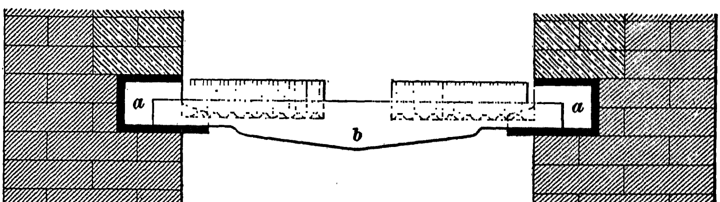


FIG. 23

ends rest on the bottom of the box *a*. This allows the grate bars and the bearer bars free expansion and contraction; also, the grate bars and bearer bars can be easily replaced when burnt out or broken.

29. Disadvantages of Stationary Grates.—The greatest objection to stationary grates is that with them the furnace door must be kept open for a considerable length of time when the fire is being cleaned, and ashes and clinker must be removed through the fire-door, causing dust and dirt. Ashes and cinders will collect on the grate, shut off the air supply to the fuel bed, and thus affect the combustion and generation of steam; the fire therefore needs frequent cleaning, which taxes the fireman severely, owing to the intense heat to which he is exposed. Also, there is an inrush of cold air into the furnace, which reduces the furnace temperature and chills the boiler plates,

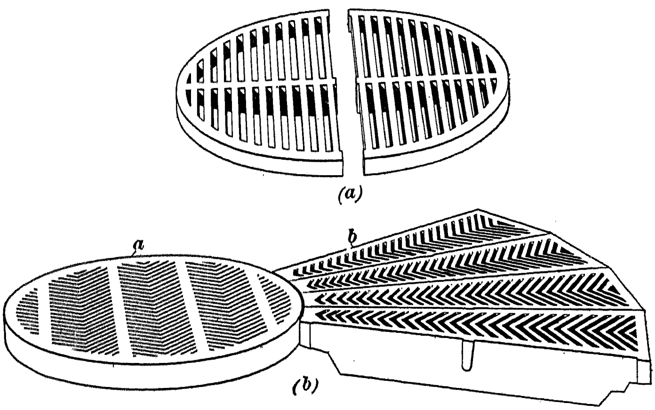


Fig. 24

thus producing stresses that cause the boiler plates and brick walls to contract and possibly crack. To overcome these conditions, grates have been designed that allow the fire to be cleaned without opening the fire-door for such long periods.

30. Grates for Vertical Boilers.—Stationary grates for vertical boilers are also made in sections, so as to take care of the expansion and contraction stresses, thus reducing warping and breakage of grate bars. In Fig. 24 (*a*) is shown a typical two-section grate. Grates of this type are made circular and are divided into two, three, or four sections, depending on the diameter required. For the larger sizes of vertical boilers, the grate is made as shown in (*b*), its center *a* being a round section

and the segments *b* of the herring-bone pattern. The segments radiate from the round center *a*, and are supported by a ring that rests on lugs attached to the boiler shell.

SHAKING GRATES

31. Advantages of Shaking Grates.—With stationary grates, the fires are cleaned by tools inserted through the fire-door; consequently, during the cleaning period a large amount of cool air is admitted to the furnace, lowering its temperature and that of the gases, and causing contraction of the plates and setting. Shaking grates eliminate these troubles, because they are so constructed that the fires may be cleaned by moving levers outside the boiler setting. The grate bars of a shaking grate are hung on trunnions at the ends and rocked on the trunnions. The result is that the fuel bed is broken up, and the ashes beneath the live coal are shaken through into the ash-pit. Either anthractite or bituminous coal may be burned on shaking grates, and the cheaper grades may be used to better advantage on shaking grates than on fixed grates. The principle of construction of shaking grates of different makes is the same, but the details may differ.

32. Description of Grates.—One form of shaking grate is shown in Fig. 25. It consists of a number of transverse parallel bars having trunnions at the ends, by which they are supported and on which they may be swung. The lower arms of the grate bars are connected by the bars *a* and *b*. Ordinarily they stand as shown in the right-hand half of the illustration. When it is desired merely to shake the fire and thus remove the bottom layer of ashes, the points *c* are moved from the level shown to the lowest position the connections will permit. The points follow the back of the bar immediately in front of them; thus no unusual opening is made through which fine fuel may fall into the ash-pit. The end bar *d* is curved to fit the frame. When the ashes have accumulated to a considerable thickness, or when they have fused together in a mass of clinkers, the points *c* are thrown upwards, as shown in the left-hand half of

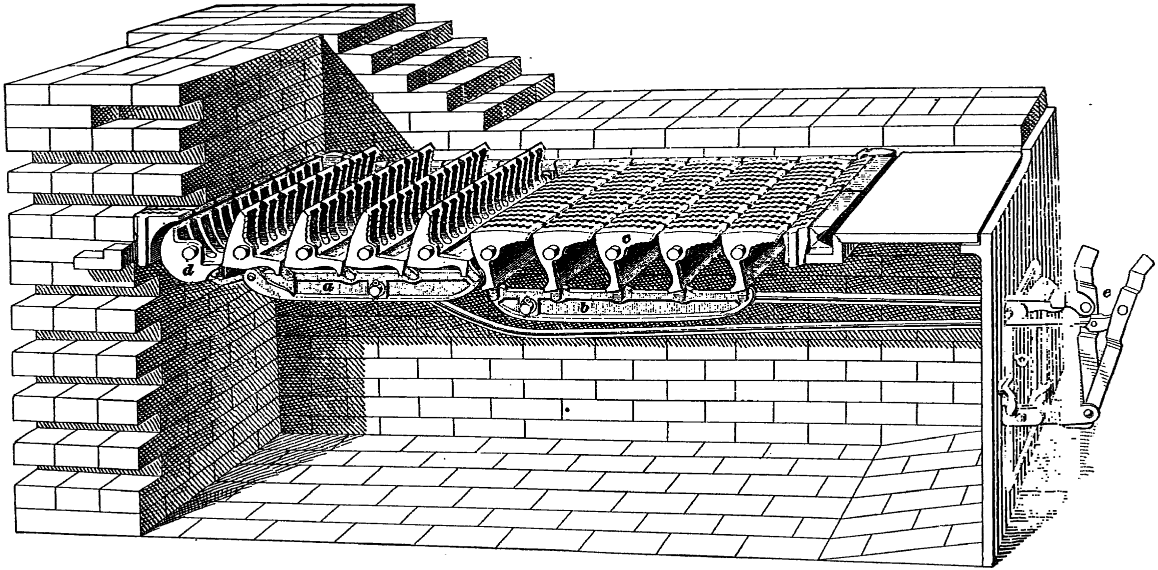


Fig. 25

the illustration, thus forming a series of deep pockets that are closed at the bottom by the main rib, or back plate, of the grate bars. The act of throwing the points upwards breaks up the fused masses, which drop into the pockets and are discharged when the bars are returned to their normal position.

33. The grate bars in Fig. 25 are operated by means of a handle fitting the levers shown at *e*. By means of these levers, either half of the grate can be shaken independently, making it possible to clean one half of the fire at a time, without opening

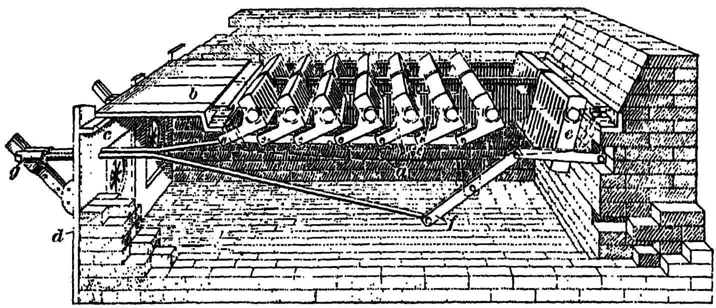


FIG. 26

the fire-door. The two levers can, however, be locked together and all the grate bars worked back and forth simultaneously. In Fig. 26 is shown another type in which the grate is divided into right and left halves, or sections. Either side can be shaken or dumped independently of the other. The trunnion bar or bearer bar *a* that supports the ends of the grates is shown merely by dotted lines so as to disclose the arrangement of the grate bars and how they are linked together. The plate *b* is the dead plate and it rests on the rib *c* of the boiler front *d* and supports the bearer bar *a*. A dump plate *e* is placed at the rear for removing clinkers that cannot be broken by shaking the grate bars. The dump plate is operated by a link *f* that can be rocked back and forth by the shaker lever at *g*.

SETTINGS FOR STEAM BOILERS

GENERAL FEATURES

34. Foundations and Walls.—A firm foundation is necessary for a boiler setting, because of the weight of the walls and the boiler structure. The nature of the soil that supports the foundation is therefore an important factor to be considered, as a yielding base will lead to settling and subsequent cracking of the walls. If soft ground is encountered, piles may be driven and these then covered with a reinforced-concrete footing about 2 feet thick, over the area on which the setting is to be built.

The side and end walls of the setting should be not less than 12 inches thick and should be lined with refractory firebrick or cement in those parts exposed to the flames and hot gases from the furnace. These walls have been built of concrete, but as a rule they are made of well-burned red brick laid with a high-grade heat-resisting cement. The ash-pit, bridges, arches, and combustion-chamber floor are also made of red brick, those parts subjected to heat being lined with a refractory cement or firebrick, the latter laid in cement of the same quality as the brick. The joints in firebrick structures should be thin.

35. Firebrick.—Standard firebrick are 9 inches in length and are made in various shapes, as shown in Fig. 27. To test the quality of a firebrick, it should be broken into two parts; in a low-grade brick the fracture will be fine and uniform, but in brick of better quality the facture appears flinty and clean. The temperatures at which firebrick will melt, or fuse, depends on the quality of the material and ranges from 2,500° to 3,700° F.; however, the fusing temperature is not a guide to the fitness of the brick to resist crushing,

erosion, and wear—points that must be considered in the case of brick for furnaces. A cubic foot of firebrick wall requires seventeen 9-inch straight bricks. If arch bricks, wedge bricks,

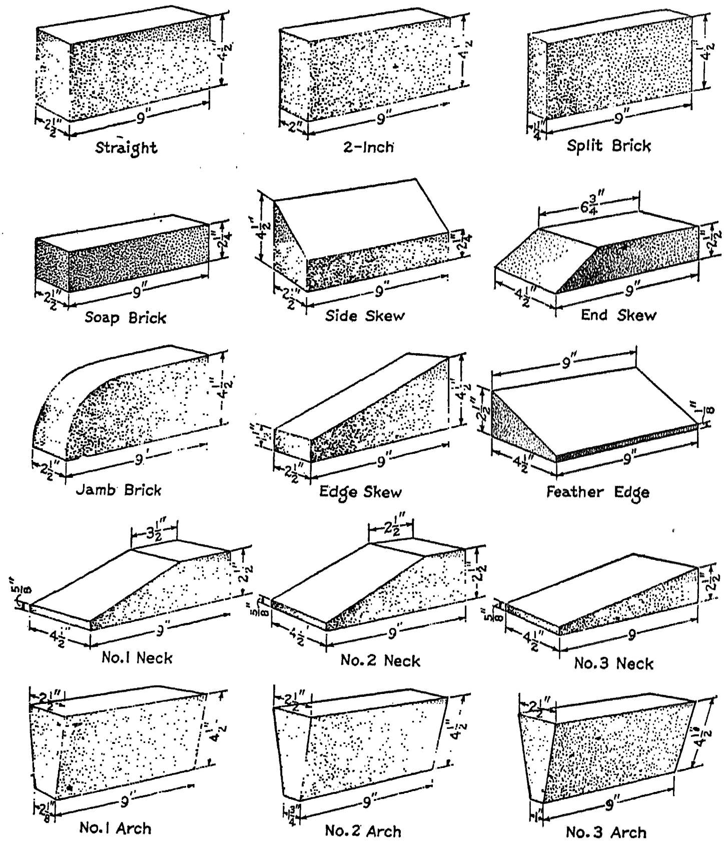


Fig. 27

or other special shapes are used, the quantity required may be taken as 10 per cent. more than for straight bricks. In laying common red brick, it is well to allow 9 cubic feet of sand and 3 bushels of lime for laying 1,000 bricks.

SETTINGS OF RETURN-TUBULAR BOILERS

DETAILS OF BRICKWORK

36. Forms of Wall Construction.—Four standard forms of wall construction for the settings of return-tubular boilers, recommended by the Hartford Steam Boiler Insurance Company, are shown in Fig. 28. Each view represents a section of one side wall taken along a vertical plane crosswise of the boiler setting, and the dimensions are clearly indicated. The construction shown in (*a*) consists of an outer wall 8 inches

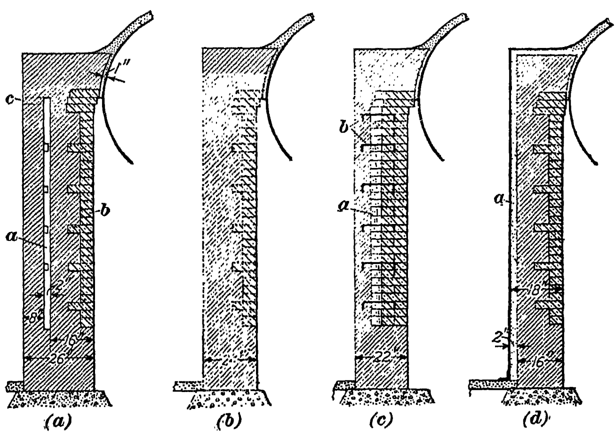


FIG. 28

thick and an inner wall 16 inches thick separated by a 2-inch air space *a* throughout the greater part of their height. The inner and outer walls are joined at top and bottom, and that part of the inner face exposed to hot gases is lined with firebrick *b*. The air space hinders the conduction of heat outwards through the walls and thereby assists in preventing cracks in the outer wall, through which air would leak into the furnace and combustion chamber. While the walls are being built, vent pipes *c* are set in the brickwork so as to lead from the air space to the outside. These are plugged after the setting has dried thoroughly.

37. The type of wall shown in Fig. 28 (*b*) is solid throughout and is practically as expensive to build as the one just

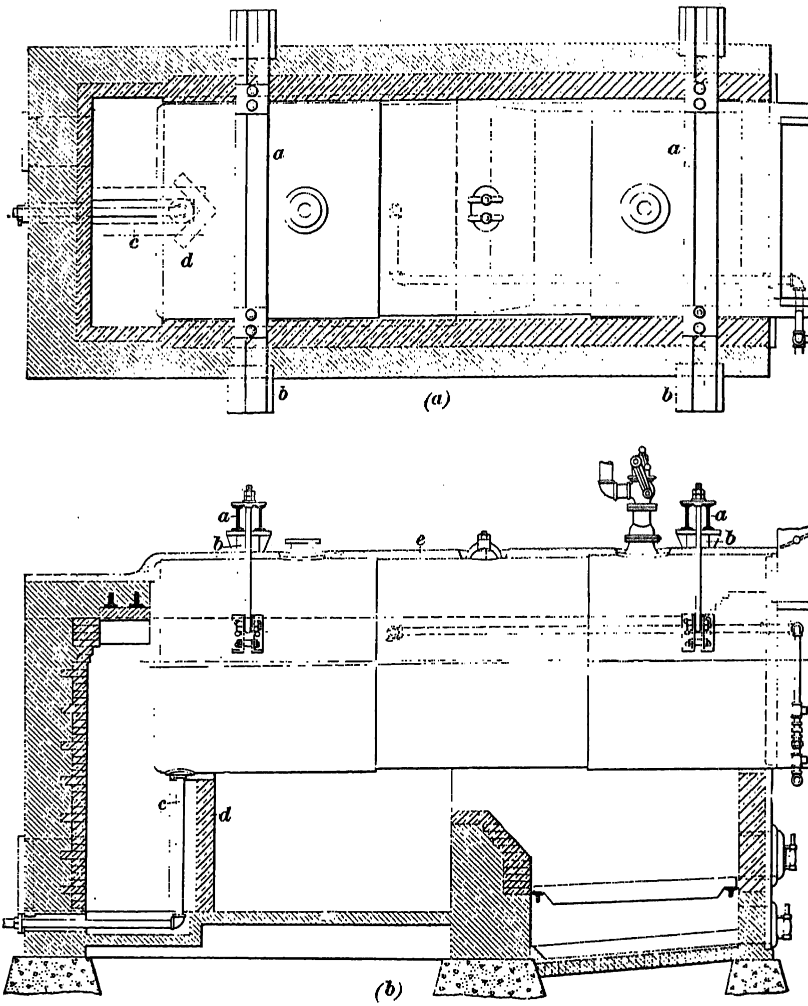


FIG. 29

described. As the heat of the furnace affects the entire wall, cracks are more likely to develop in the solid wall than in the wall with an air space. The construction shown in (*c*)

consists of an outer wall of common red brick and an inner wall of firebrick separated by a single thickness of insulating brick *a*. The insulating bricks are of a special heat-resisting type and are used to reduce the conduction of heat outwards through the setting. They are of standard size but are not so strong as ordinary brick; therefore, metal ties of the form shown at *b* are used to bind the inner and outer walls together. In the case of boilers set in a battery, the division wall between adjacent boilers may be made as in (*c*), using firebrick for both faces, however, and separating them by insulating brick.

38. The boiler wall shown in Fig. 28 (*d*) is like that in (*b*) except that its thickness is considerably less. Also, the entire outside of the setting is surrounded by a casing *a* made of steel plate, and the 2-inch space between the brickwork and the casing is filled with some good form of insulating material,

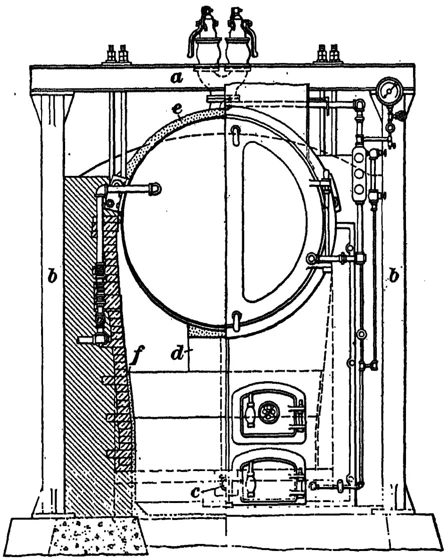


FIG. 30

such as magnesia or asbestos. A setting of this kind is expensive to build, but it can be made practically air-tight, thereby insuring favorable conditions for economical operation.

In all four of the forms shown, it will be observed that the top of the wall is not built directly against the boiler shell; instead, a clearance of about 1 inch is left, and this space is filled with asbestos rope. If the brickwork were built against the boiler, the expansion and contraction of the shell would eventually cause cracks to develop in the setting. The asbestos rope forms a compressible joint and at the same time prevents inward leakage of air.

39. General Arrangement of Boiler.—The general arrangement of a return-tubular boiler and its setting is shown in Fig. 29; (*a*) is a plan view from above, the walls being shown in section at the level of the center line of the boiler; (*b*) is a partial longitudinal section taken in a vertical plane through the center line; and Fig. 30 is a combined end view and transverse section. The boiler is supended from the transverse girders *a*, which are supported by the cast-iron columns *b* outside the walls. The rear end of the boiler is $1\frac{1}{2}$ inches lower than the front end, so that sediment will naturally collect at the rear, where it may be removed through the blow-off pipe *c*. This pipe is protected from the direct action of the hot gases by a **V**-shaped brick pier *d* built in front of it. The horizontal part of the pipe, leading out through the rear wall, is contained in a trench in the floor and is covered with a steel plate or loose bricks. The part of the boiler shell not enclosed by brickwork is covered with a layer of non-conducting material *e* from 2 to 3 inches thick, over the surface of which is spread a thin coat of Portland cement. A clearance of 1 inch is left between the ends of the bridge wall and the side walls, to allow for expansion, as shown at *f*, and the space is filled with asbestos rope.

SUPPORTS FOR RETURN-TUBULAR BOILERS

40. Columns.—Either cast-iron or steel columns may be used to support the cross-beams from which the boiler is suspended. Four columns are required, and they are set outside the brickwork and rest on suitable footings. Three boilers 78 inches in diameter may be supported by one set of four

columns. If the columns are of cast iron, they may be of hollow round or square cross-section; if of steel, an **H** section should be used. The ordinary **I** beam is not suitable, as it is too weak under compressive loads. In Tables II, III, and IV, prepared by the Hartford Steam Boiler Insurance Company, are given the dimensions of cast-iron and steel columns to be used in supporting one, two, or three boilers of a given size, on the assumption that four columns are used. The lengths given for the columns are maximum allowable values and should not be exceeded.

TABLE II

PROPORTIONS OF ROUND CAST-IRON COLUMNS

Diameter of Boiler Inches	Length of Tubes Feet	Length of Column Ft.	Length of Column In.	1 Boiler Diameter	1 Boiler Thickness	2 Boilers Diameter	2 Boilers Thickness	3 Boilers Diameter	3 Boilers Thickness
54	16	10	6	7	$\frac{3}{4}$	7	$\frac{7}{8}$	7	1
60	16	11	0	7	$\frac{3}{4}$	7	$\frac{7}{8}$	7	1
60	18	11	0	7	$\frac{3}{4}$	7	$\frac{7}{8}$	7	1
66	16	12	0	8	$\frac{7}{8}$	8	1	8	$1\frac{1}{8}$
66	18	12	0	8	$\frac{7}{8}$	8	1	8	$1\frac{1}{8}$
72	16	13	0	9	$\frac{7}{8}$	9	1	9	$1\frac{1}{8}$
72	18	13	0	9	$\frac{7}{8}$	9	1	9	$1\frac{1}{8}$
72	20	13	0	9	$\frac{7}{8}$	9	1	9	$1\frac{1}{8}$
78	16	13	6	9	$\frac{7}{8}$	9	1	9	$1\frac{1}{8}$
78	18	13	6	9	$\frac{7}{8}$	9	1	9	$1\frac{1}{8}$
78	20	13	6	9	$\frac{7}{8}$	9	1	9	$1\frac{1}{8}$
84	18	14	0	9	$1\frac{1}{8}$	9	$1\frac{1}{8}$	9	$1\frac{1}{8}$
84	20	14	0	10	1	10	1	10	$1\frac{1}{8}$

41. Cross-Beams.—The transverse beams from which the boiler is suspended, in the case of a setting like that shown in Figs. 29 and 30, may be arranged as shown in the sectional view, Fig. 31. Each transverse support consists of two **I** beams *a* placed side by side and held together by bolts *b* that pass through distance pieces *c*. These distance pieces fit the outline of the beams, and the **I** beams are thus held at a fixed distance from each other. Short sections of pipe slipped over the bolts will serve the same purpose. Across the tops of the

TABLE III

PROPORTIONS OF SQUARE CAST-IRON COLUMNS

Diameter of Boiler Inches	Length of Tubes Feet	Length of Column Ft.	Length of Column In.	1 Boiler Width	1 Boiler Thickness	2 Boilers Width	2 Boilers Thickness	3 Boilers Width	3 Boilers Thickness
				Dimensions of Column, in Inches					
54	16	10	6	6	$\frac{3}{4}$	6	$\frac{7}{8}$	6	1
60	16	11	0	6	$\frac{3}{4}$	6	$\frac{7}{8}$	6	1
60	18	11	0	6	$\frac{3}{4}$	6	$\frac{7}{8}$	6	1
66	16	12	0	7	$\frac{3}{4}$	7	$\frac{7}{8}$	7	1
66	18	12	0	7	$\frac{3}{4}$	7	$\frac{7}{8}$	7	1
72	16	13	0	8	$\frac{3}{4}$	8	$\frac{7}{8}$	8	1
72	18	13	0	8	$\frac{3}{4}$	8	$\frac{7}{8}$	8	1
72	20	13	0	8	$\frac{3}{4}$	8	$\frac{7}{8}$	8	1
78	16	13	6	8	$\frac{3}{4}$	8	$\frac{7}{8}$	8	1
78	18	13	6	8	$\frac{3}{4}$	8	$\frac{7}{8}$	8	1
78	20	13	6	8	$\frac{3}{4}$	8	$\frac{7}{8}$	8	1
84	18	14	0	8	1	8	1	8	$1\frac{1}{8}$
84	20	14	0	8	1	8	1	8	$1\frac{1}{8}$

TABLE IV

PROPORTIONS OF H-BEAM COLUMNS

Diameter of Boiler Inches	Length of Tubes Feet	Length of Column Ft.	Length of Column In.	1 Boiler Depth Inches	1 Boiler Weight Per Foot Pounds	2 Boilers Depth Inches	2 Boilers Weight Per Foot Pounds	3 Boilers Depth Inches	3 Boilers Weight Per Foot Pounds
				Proportions of Column					
54	16	10	6	5	18.7	5	18.7	6	23.8
60	16	11	0	5	18.7	6	23.8	8	34.0
60	18	11	0	5	18.7	6	23.8	8	34.0
66	16	12	0	5	18.7	8	34.0	8	34.0
66	18	12	0	5	18.7	8	34.0		
72	16	13	0	6	23.8	8	34.0		
72	18	13	0	6	23.8	8	34.0		
72	20	13	0	6	23.8	8	34.0		
78	16	13	6	6	23.8	8	34.0		
78	18	13	6	6	23.8	8	34.0		
78	20	13	6	8	34.0				
84	18	14	0	8	34.0				
84	20	14	0	8	34.0				

beams is laid a bearer plate *d* through which pass the ends of the eyebolt hangers *e*. The loop at the lower end of the hanger fits over a pin in the bracket on the side of the boiler. The upper ends of the hangers are threaded and fitted with nuts *f* that rest on the bearer plate. The upper nuts are locknuts. In Table V are given the proportions of I beams to be used for supporting one, two, or three boilers. It is understood that four beams are used, set in pairs—two at the front end of the boiler and two at the rear. The ends of each pair rest on the tops of the supporting columns.

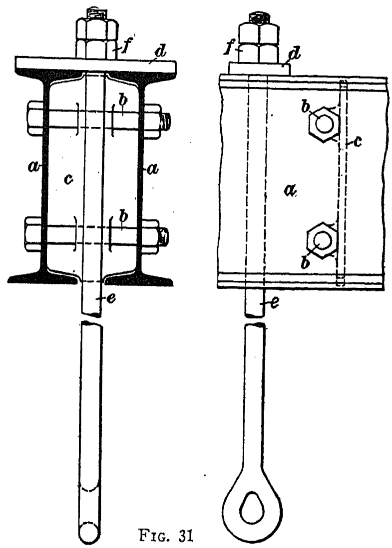


FIG. 31

TABLE V

PROPORTIONS OF CROSS-BEAM SUPPORTS

Diameter of Boiler Inches	Length of Tubes Feet	1 Boiler		2 Boilers		3 Boilers	
		Proportions of I Beam					
		Depth Inches	Weight Per Foot Pounds	Depth Inches	Weight Per Foot Pounds	Depth Inches	Weight Per Foot Pounds
54	16	6	12¼	10	30	15	42
60	16	7	15	12	31½	18	55
60	18	7	15	12	35	18	55
66	16	7	15	12	40	18	55
66	18	8	18	15	42	18	60
72	16	8	18	15	42	20	65
72	18	8	18	15	42	20	65
72	20	8	18	18	55	24	80
78	16	8	18	18	55	24	80
78	18	9	21	18	55	24	80
78	20	9	21	18	55	24	80
84	18	9	21	18	55	24	80
84	20	9	21	20	65	24	90

SETTINGS OF WATER-TUBE BOILERS

42. Methods of Supporting Boilers.—The construction of the side walls of the settings of water-tube boilers is similar to that of the walls for return-tubular boilers; but the methods of supporting water-tube boilers depends altogether on the type of boiler, size of installation, and local conditions. For example, the Babcock & Wilcox boiler is suspended from cross-beams that rest on columns, the suspending rods forming loops beneath the steam drum at the front and the rear. The Heine boiler is supported by the front and rear walls of the setting, the water legs at the front and the rear resting directly on plates set into the brickwork. The Edge Moor boiler may be suspended from overhead cross-beams or it may be supported by short columns riveted to the water legs at the front and the rear. Similar methods are used with the various other types of water-tube boilers.

43. Baffles.—To direct the flow of hot gases around and over the tubes of water-tube boilers, it is the practice to build baffles between or across the tubes. The gases are thus compelled to make a longer circuit inside the setting and give up a greater percentage of their heat. Baffles are commonly built of tiles made in suitable form and size to fit the particular type of boiler in which they are to be used.

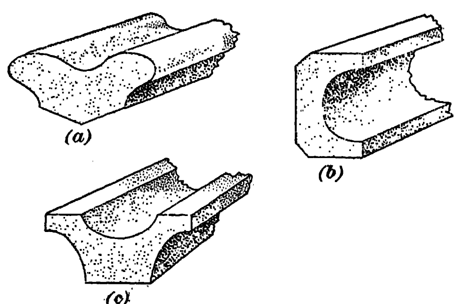


Fig. 32

Three forms of tiles are illustrated in Fig. 32 (*a*), (*b*), and (*c*), these being known as **B**, **L**, and **T** tiles, respectively. They are intended to be used, primarily, in boilers that have horizontal tubes, or tubes nearly horizontal. Another way of building baffles is to make them of a plastic refractory material that is put in place while wet. After it has dried and has become hardened by the heat, it forms a one-piece baffle.

44. Baffles are arranged in different positions, varying from horizontal to vertical. The position and condition of the baffles have much to do with the successful operation of the boiler. The design of a boiler may be good and the gas area through the setting may be correct; but if the baffles are improperly installed, the operation of the boiler will be faulty. The boiler setting should be such that the gases circulate freely around the tubes, without having any corners or pockets in which the gases collect and fail to circulate. Such pockets of dead gas lead to poor circulation of the gases and reduce the effective heating surface of the boiler.

MECHANICAL STOKERS

DEVELOPMENT AND CLASSIFICATION

45. Development of Mechanical Stoker.—The earliest mechanical stoker is thought to have been invented by Watt, who obtained a patent in 1785 on a simple device for pushing the coal, after it had been coked, from the front of the grate back toward the bridge. Since that time English engineers have invented a large number of stokers, some of which have been extensively used and have given satisfactory results when applied under proper conditions. None of the English designs have been much used in the United States, but a number of American designs of mechanical stokers and automatic furnaces, differing more or less from the earlier English types, have been developed since 1873, and several have been put into extensive use.

46. Advantages and Disadvantages of Stokers.—Numerous tests have shown that a careful and intelligent fireman with a properly designed furnace can obtain as good results, so far as economy in the use of fuel is concerned, as have ever been obtained with any mechanical stoking device; it is also certain that hand firing may be so regulated as to produce practically smokeless combustion. It is well known, however, that these possible results are not generally attained in every-

day work; nor can they be obtained for long periods by hand firing when the boilers are operated at two or three times their normal capacity. Boiler firing is hard and, in many cases, far from pleasant work. Most boiler rooms are hot and many are poorly lighted and ventilated—conditions that make it difficult for any but the best of men to keep up their interest in their work.

47. With the best automatic stokers the fireman is relieved from much of the most severe and difficult part of his work; he is thus more free to devote suitable care and attention to the operation of the furnace. The coal is fed to the furnace at a uniform rate and in such a manner that the gases distilled from it are thoroughly mixed with a proper supply of air; the gases are then conducted through a part of the furnace in which there is a high enough temperature to insure their complete combustion. When the coal supply and air supply are properly adjusted to suit the working conditions, the continuous and uniform manner in which the fuel is fed to the furnace insures a high and practically uniform temperature, which is favorable for the complete combustion of the gases and relieves the boiler from the stresses produced by the sudden changes in temperature that occur when cold air enters the fire-door during hand firing.

48. Economic Considerations.—Automatic furnaces are more expensive, in both first cost and maintenance, than furnaces for hand firing, and in small plants they save little or nothing in the cost of labor; in these cases the question of economy in their use depends on the possibility of a saving in coal and of wear and tear on the boiler. In the matter of coal they have the advantage of successfully burning cheap grades of fuel that could not be used with ordinary methods of hand firing. Automatic furnaces will give better results in the matter of smoke prevention than can be obtained by hand firing, unless an unusual degree of care and attention is given to the management of the fires. In large plants, especially where some of the modern systems of coal- and ash-handling machinery are used, automatic furnaces effect a very considerable

saving in labor; this, in addition to their other points of superiority, makes them more economical than hand firing.

49. Classification of Stokers.—The principal designs of mechanical stokers and automatic furnaces may be divided into three general classes; namely, the *overfeed stoker*, the *underfeed stoker*, and the *traveling-grate*, or *chain-grate*, *stoker*. In the first the coal is slowly fed by some suitable mechanical device on a coking plate, where the volatile matter is distilled off by the heat of the furnace and mixed with a suitable supply of air. The coke so formed is then fed forwards on to grates, where it is burned. The mixture of gas and air is burned in a suitable combustion chamber, usually in as close proximity as is practicable to the bed of burning coke.

In the second class the coal is forced by some mechanical device into a chamber *under* the mass of burning fuel in the furnace. The volatile matter is here distilled off and mixed with a supply of air. The coke formed is pushed upwards by the fresh coal that is fed into the chamber and burns above the coking chamber and on suitable grates at the sides, on which it falls. The mixture of gas and air rises through the bed of burning coke above the coking chamber and, being highly heated and thoroughly mixed, burns readily.

The chain-grate, or traveling-grate, stoker consists of an endless belt composed of grate bars that travel over front and rear sprockets. Coal is fed from hoppers by gravity and is ignited under a combustion arch called an *ignition arch*. As combustion takes place the burning fuel travels toward the rear end of the furnace with the grate, which is regulated to the proper speed for burning the fuel. The ashes are dumped at the rear end of the grate to an ash-pit or an ash conveyer.

50. Finding Size of Stoker.—In order to determine the size of stoker required for a given boiler, the steam-generating capacity of the boiler and the kind and quality of fuel to be used must be known. From these data it will be possible to estimate the rate of combustion and hence the number of square feet of grate area required. A stoker can then be selected to give this required area. As boilers differ in design, there is no fixed

relation between the length and width of the furnace. Each case must be considered as an individual problem. The customary method is to supply the stoker manufacturer with all the data as to type and size of boiler, kind of fuel, nature of service, maximum rate of steam generation, and so on, and let him provide a stoker to meet the conditions.

OVERFEED STOKERS

51. General Construction of Overfeed Stoker.—The overfeed stoker usually consists of an inclined grate made up of a series of bars, part or all of which may be movable. The fuel is fed on to the inclined grate at the upper end, after passing over a dead plate on which it is partly coked, or deprived of its volatile matter. The burning fuel then moves down the incline, burning as it descends, its movement being caused by the inclined position of the grate as well as by a slight rocking or tilting of some or all of the grate bars. By the time the fuel has reached the bottom of the incline, it is completely burned, and the ashes are dumped into a pit. The hopper from which fresh fuel is supplied to the stoker may be at the front or at the side of the furnace, and so the stoker may be of the front-feed type or of the side-feed type.

52. Roney Stoker.—The Roney stoker, shown in Fig. 33, is an overfeed stoker of the front-feed type. The coal is fed into the hopper *a*, at the bottom of which is an inclined pusher plate *b* to which a slow reciprocating movement is given by an eccentric mounted on the shaft *s*. At each inward movement of the pusher plate a quantity of fresh coal is pushed down and inwards upon the dead plate *c*, where it is subjected to the heat of the furnace and has most of its volatile matter driven off. The pressure of the fresh fuel fed from the hopper causes it to fall upon the stepped grate bars *d*, which run crosswise of the furnace and are supported by end trunnions. By the time the coal has reached the lower end of the inclined grate, all combustible matter has been burned and only ashes and clinkers remain, these collecting on the dump plate *e*. The dump plate

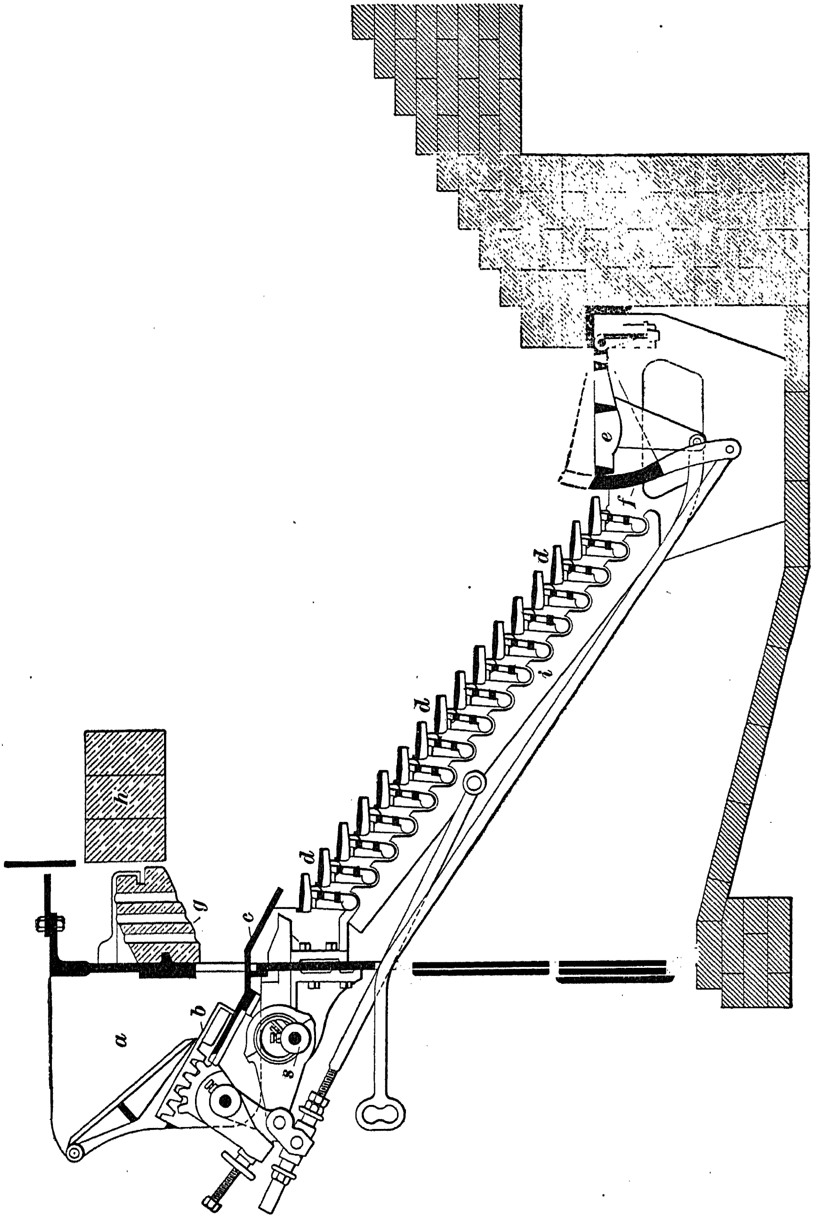


FIG. 33

is hinged at its rear edge, next to the bridge wall, and may be dropped by moving a hand lever that extends to the boiler front. The ashes are thus dumped into the ash-pit. To prevent fuel from sliding off the grate and going into the ash-pit when the dump plate is lowered, a curved guard *f*, also hinged at the bridge wall, is raised to the upper dotted position by moving the handle shown, and is lowered after the dump plate has been brought back into normal position.

53. As combustible gases are driven off during the coking of the fuel on the dead plate *c*, Fig. 33, air for their combustion may be admitted through hollow tile *g*. To maintain a high temperature in the furnace and promote efficient combustion, a firebrick arch, part of which is shown at *h*, may be built above the grate. The lower end of each grate bar *d* fits into a rocker bar *i* to which a reciprocating motion is given by the same eccentric that drives the pusher plate. The bars *d* are thus rocked on their end trunnions, and this rocking assists in causing the fuel to move down the grate. This stoker is designed especially for burning all grades of bituminous coal, but it may be used successfully for burning fine anthracite. It operates with natural draft and the rate of combustion of coal varies from 35 pounds per square foot of grate area per hour in the case of coking fuels to 50 pounds per hour in the case of free-burning fuels.

54. Wilkinson Stoker.—The Wilkinson stoker is a front-feed stoker designed more particularly for the burning of fine anthracite. In Fig. 34 it is shown applied to a horizontal return-tubular boiler, while in Fig. 35 is shown an enlarged view of the grate itself. Like parts have been lettered the same in both illustrations. The grate bars *b* are cast hollow, with nearly horizontal openings leading from the interior through the risers of the steps that form the upper surface; these openings are shown in the black sectional portion of the left end of the bar. To each grate bar is given a to-and-fro motion in a horizontal direction by the rock shaft *f* and links *g*, Fig. 34, the ends of the bars being supported by, and sliding on, the hollow cast-iron bearing bars *d*. A pusher *i*, Fig. 35,

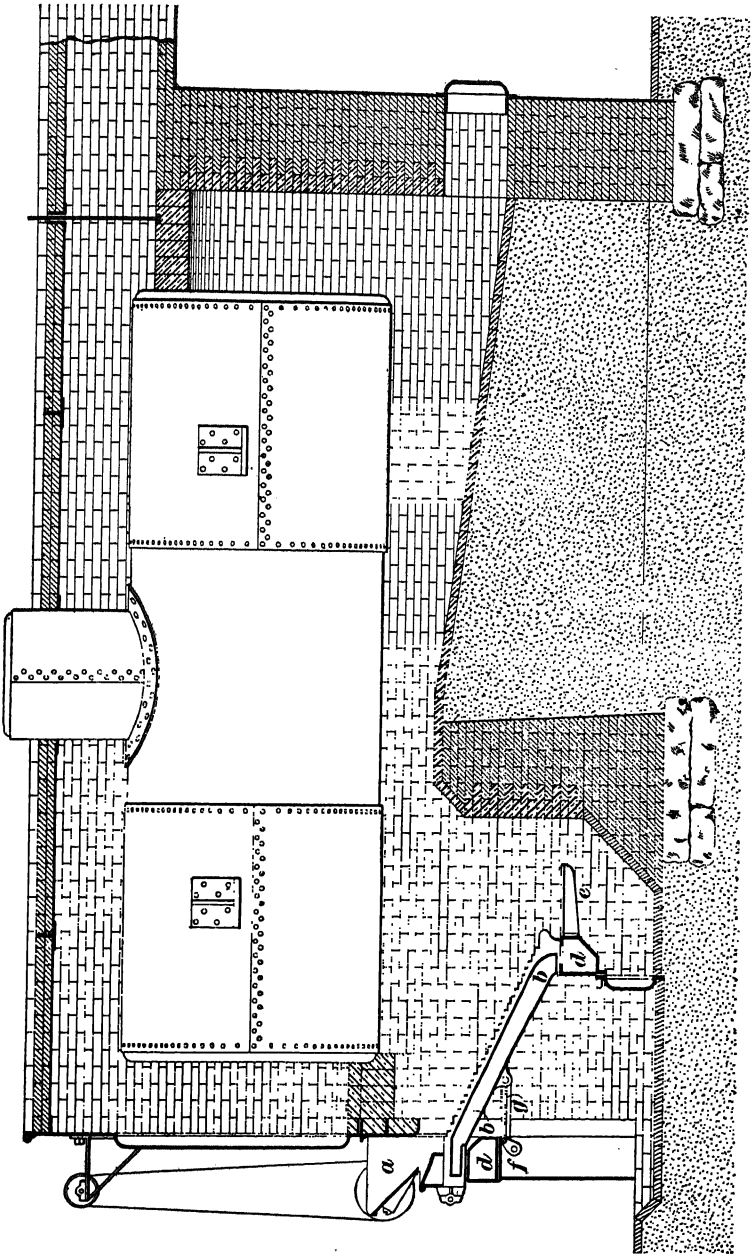


FIG. 34

fastened to the upper end of each grate bar, pushes the coal from the hopper *a* through the opening in the furnace front onto the bars.

55. The motion of the grate bars, Fig. 35, gradually forces the coal downwards and deposits the ashes and clinkers on the clinker grates *e*, from which they are finally pushed into the ash-pit. Practically all the air for the combustion of the coal is drawn into the upper ends of the hollow grate bars by the steam jets *c*, and forced into the fire from the openings in the

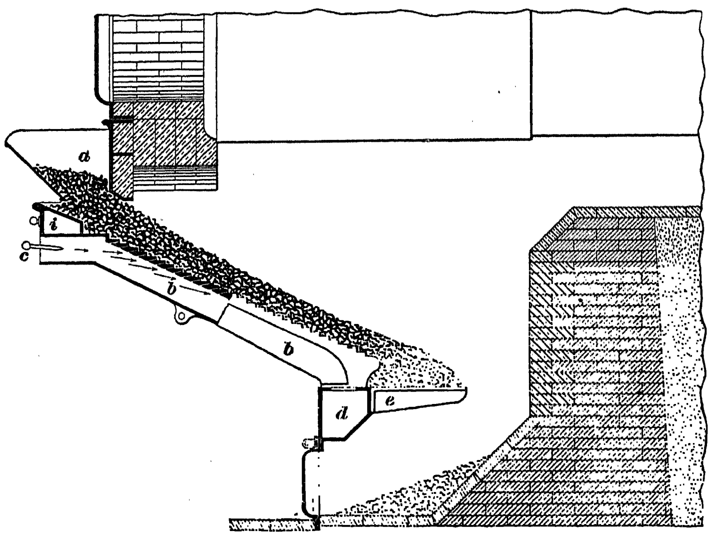


FIG. 35

tops of the bars. In this case, the steam jets, in addition to furnishing draft, serve an important purpose in keeping the bars moderately cool, thus preventing both their destruction by the heat and the sticking of the clinker, which with anthracite often causes considerable trouble if no special provision is made to overcome it. The advantages derived from this use of the steam jet are considered of sufficient importance to more than balance any possible loss of heat, and it is recommended by the makers that the steam be used, even where sufficient chimney draft is available to burn the fuel.

56. Murphy Automatic Furnace.—The Murphy automatic furnace is an overfeed stoker of the side-feed type. The general features of the furnace are shown in the cross-section, Fig. 36. The coal hoppers *a* are located above and on each side of the sloping grates. To facilitate proper operation, the fuel should be in a finely divided condition, such as that of bituminous slack. The coal is fed atomatically by gravity to the

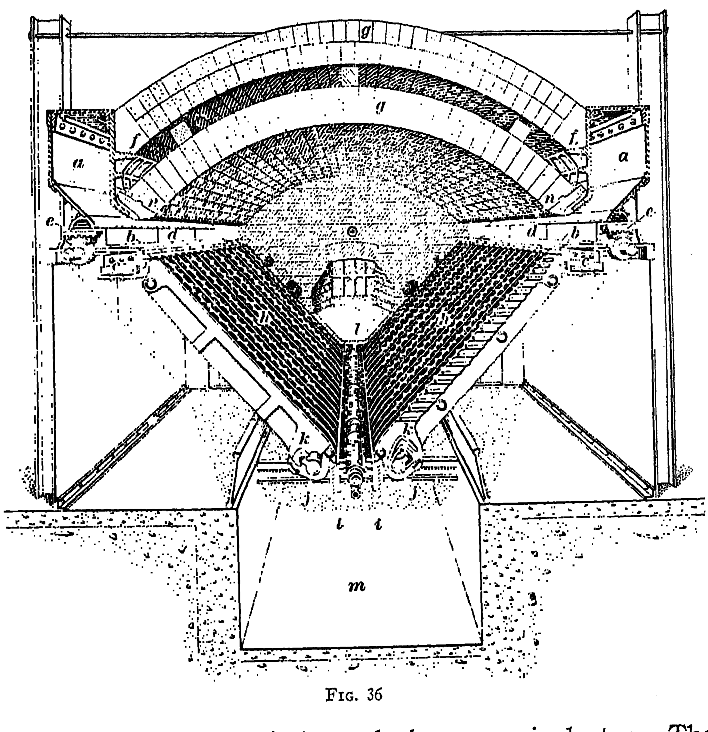


FIG. 36

coking plate *b*, which is located above an air duct *c*. The circulation of air through the duct *c* prevents the coking plate from burning away. Pusher blocks *d* move the coal onto the coking plate, by the reciprocating motion produced by the rack and sector gearing *e*. The speed of this feed mechanism can be regulated according to the desired rate of combustion. As the gases from the coking fuel are expelled, they immediately mix with heated air admitted through openings in the arch

plate f and burn. After the coked fuel has been pushed from the plate b, it travels slowly down the sloping grates h, and during this movement of the fuel bed, air is supplied through the grates.

57. The grate bars are arranged alternately in pairs, each pair consisting of a stationary bar and a movable bar. The stationary bar, Fig. 37 (a), is ribbed on both sides with projections a that break up the air supply into many small jets and also prevent the fine coal from dropping through into the ash-pit unburned. Near the bottom of the bar the ribs a are omitted, as at this point the fuel has gone through the coking stage, and a more liberal amount of air is needed. The stationary bars, as shown in Fig. 36, rest against the air box c at the top, and at the lower end are supported by the bearer rod i. The movable grate bar, Fig. 37 (b), is a plain bar having a circular opening a that fits over the pivot b of the stationary bar in (a). Movement is given to the movable bars, as shown in Fig. 36, by the rocker-shafts j, which have cams k that engage with the lower ends of the movable bars. As the rocker-shafts oscillate, the cams force the lower ends of the movable bars up and down. This action breaks up the fuel bed sufficiently to promote combustion and causes the fuel to move down on the grate.

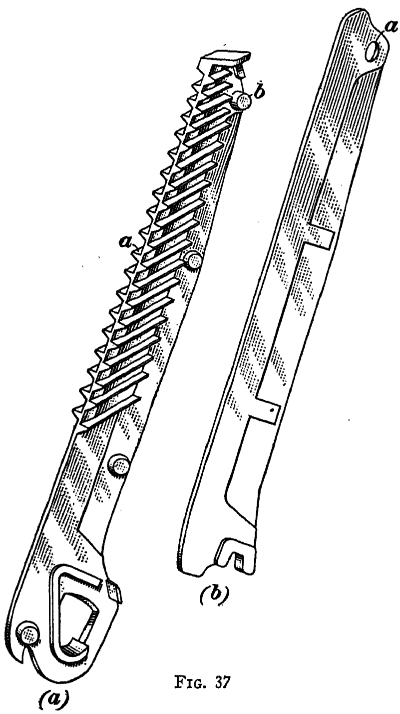


FIG. 37

58. At the bottom of the grates, Fig. 36, is a clinker breaker l that is oscillated by a link mechanism outside. The

projections on the clinker breaker force the ashes and clinker against the bottom of the grate and break up the refuse so that it will fall into the ash-pit *m* below.

The arch *g* is in two sections with an air space between them, the lower arch being made of firebrick and the upper one of

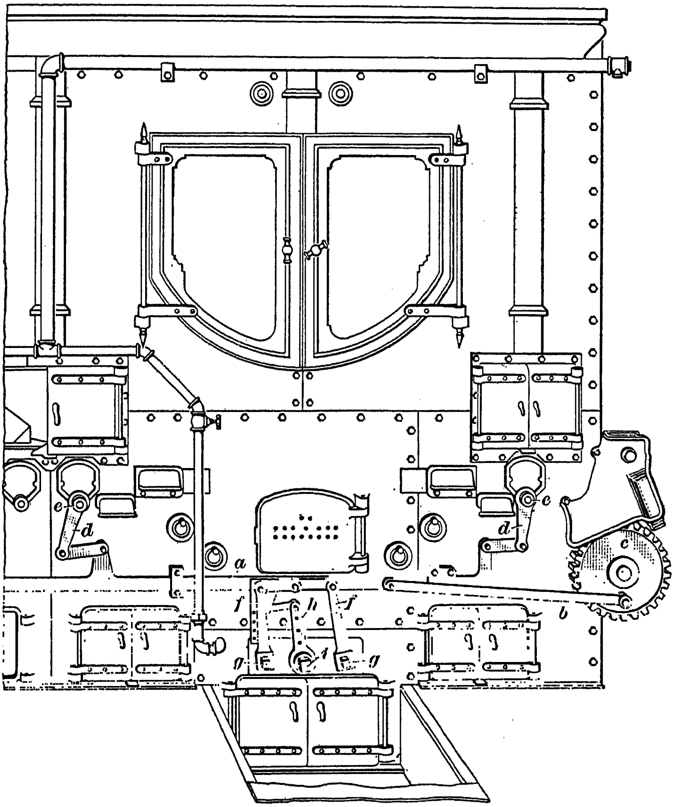


FIG. 38

common brick. Both are carried by the arch plates *f* in which are air openings *n* leading into the air space of the arch. As the air circulates through the air space it is heated and passes through the openings in the arch plate to mix with the gases from the fuel coking on the plate *b*.

59. The movable parts of the stoker are driven by an external mechanism arranged on the front of the furnace, as shown in Fig. 38. A bar *a* extends across the front and is supported by brackets. It is connected by a rod *b* to a pin on the worm-gear *c*, which is rotated by gearing driven by a motor or a small steam engine; thus, as the gear *c* rotates, there is given to the bar *a* a reciprocating movement in its supporting brackets. Links and levers *d* connect the bar *a* to shafts *e*, which are the shafts of the sectors *e* shown in Fig. 36. The reciprocating movement of the bar *a*, Fig. 38, thus causes the shafts *e* to oscillate and moves the pusher blocks *d*, Fig. 36, thereby feeding the coal to the grates. The bar *a*, Fig. 38, is also connected by levers *f* to the shafts *g*, which correspond to the shafts *j*, Fig. 36, that carry the cams which give movement to the movable grate bars. Thus the reciprocating motion of the bar *a*, Fig. 38, oscillates the shafts *j*, Fig. 36, and rocks the alternate bars of the grates. A link *h*, Fig. 38, connects the bar *a* to the clinker-breaker shaft *i*, shown at *l*, Fig. 36; thus, the shaft *l* is oscillated, resulting in the breaking up of the clinkers. The amount of swing, or oscillation, of the shaft *l* is adjustable, so that the movement may be made to suit the percentage of ash in the fuel. This type of furnace may be set directly beneath the boiler, but it is usually placed outside the main setting, like the Dutch oven.

UNDERFEED STOKERS

60. Characteristics of Underfeed Stokers.—Underfeed stokers are arranged at the front end of the boiler, with the grates in either a horizontal or an inclined position. The coal is fed from hoppers and is forced into the furnace by rotating screws or by the intermittent movement of reciprocating plungers. The principle of operation of the underfeed stoker is that fresh coal is fed from beneath the fuel bed. The volatile gases are given off as the coal passes up through the fire and are subsequently ignited in their passage. Such a system, if properly managed, brings the fuel gases and air into direct contact in the incandescent zone of the fuel bed

and thus insures excellent combustion. To burn the fuel successfully by this method, both forced and induced draft are needed. A blower system is used to force air under the grate into the fuel bed and the chimney draft should be sufficient to carry the product of combustion; if not, an exhaust fan or a steam jet is used in the chimney to increase the draft.

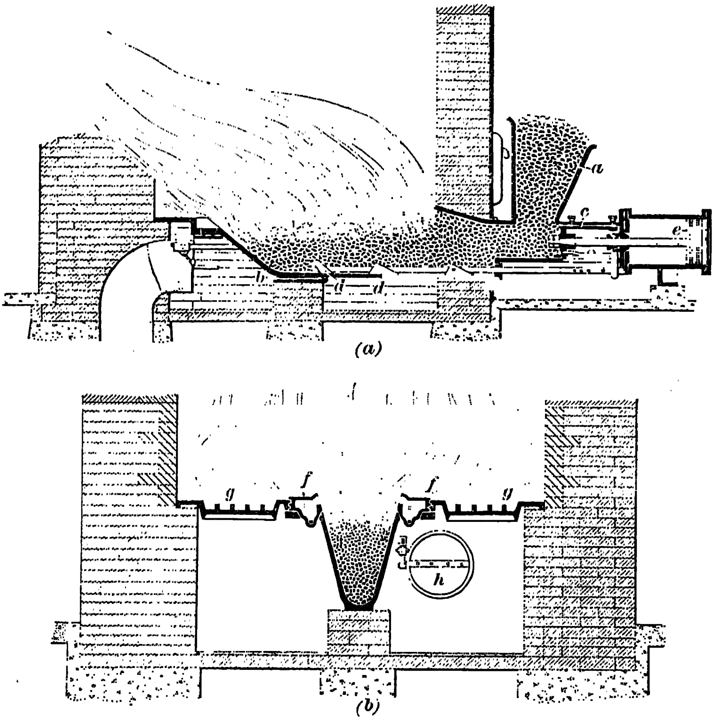


FIG. 39

61. Jones Underfeed Stoker.—The Jones underfeed stoker of the plunger type is shown in Fig. 39, (*a*) being a longitudinal section and (*b*) a cross-sectional view of the furnace and stoker. The coal is fed into the hopper *a* and is carried forwards into the retort, or fuel magazine, *b* by the action of the ram *c* and the pusher blocks *d*. The ram *c* is connected to a piston *e*

that moves forwards and backwards in a cylinder under steam pressure. The form of the retort *b* and the pusher blocks *d* is shown in Fig. 40. Along the top of the retort are hollow blocks *f* that have openings called tuyères, which permit the air to flow into the coking fuel bed. The blocks *f* are the only parts of the retort that come in contact with the fire. The cross-sectional view, Fig. 39 (*b*), shows the position of the blocks *f* and the dead plates *g* in the furnace. The air introduced under the dead plate and through the hollow blocks keeps these parts from burning out for a long period. The forward and backward movement of the ram *c* and the pusher blocks *d* forces the fresh coal to move upwards in the retort and breaks

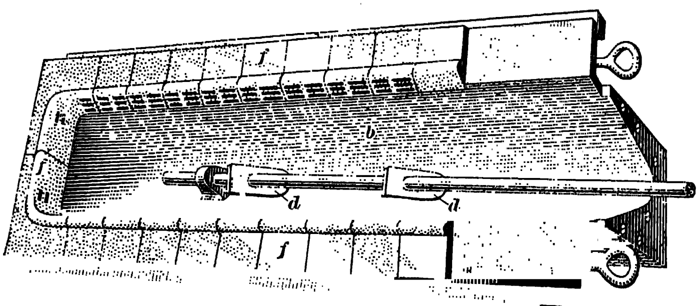


FIG. 40

up the fire, automatically slicing the fuel bed at the same time. Air is introduced under the stoker through a duct *h*, which can be opened or closed to the air blast by a blast gate controlled from the front of the furnace. The illustration shows only one unit under a boiler; but in large installations several units are arranged side by side, as in Fig. 41, the reference letters of which correspond with those of Fig. 39 in the case of corresponding parts.

62. Cleaning Jones Stoker.—As the movement of the ram continually forces the fuel back into the furnace, the ash and clinker are eventually deposited on a balanced dump plate *i*, Fig. 41. By tilting the dump plate, the ash and clinker fall to the ash-pit below, which in large installations is specially constructed with an ash-removal system. In the example

shown, the ash-pit j is so shaped that the ashes can be readily raked into small dump cars k in a tunnel under the boiler-room floor.

63. American Stoker.—The American stoker is of the underfeed type using a screw for feeding the coal. In Fig. 42

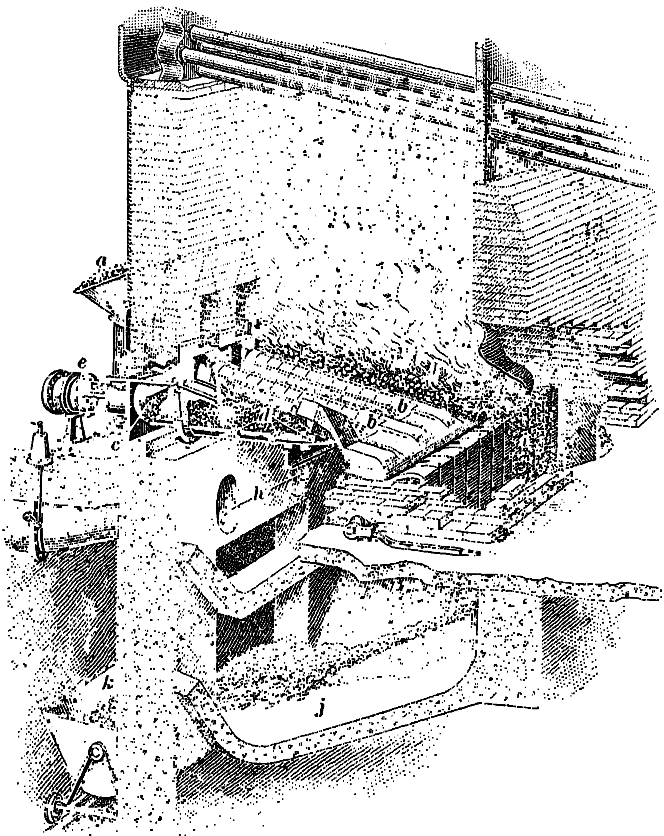


Fig. 41

are shown sectional views of such a stoker applied to a return-tubular boiler. Coal is fed into the hopper a, from which it is drawn by the spiral conveyer b and forced into the magazine d, in which it is coked. The incoming supply of fresh fuel forces the coke upwards to the surface and over the sides of the

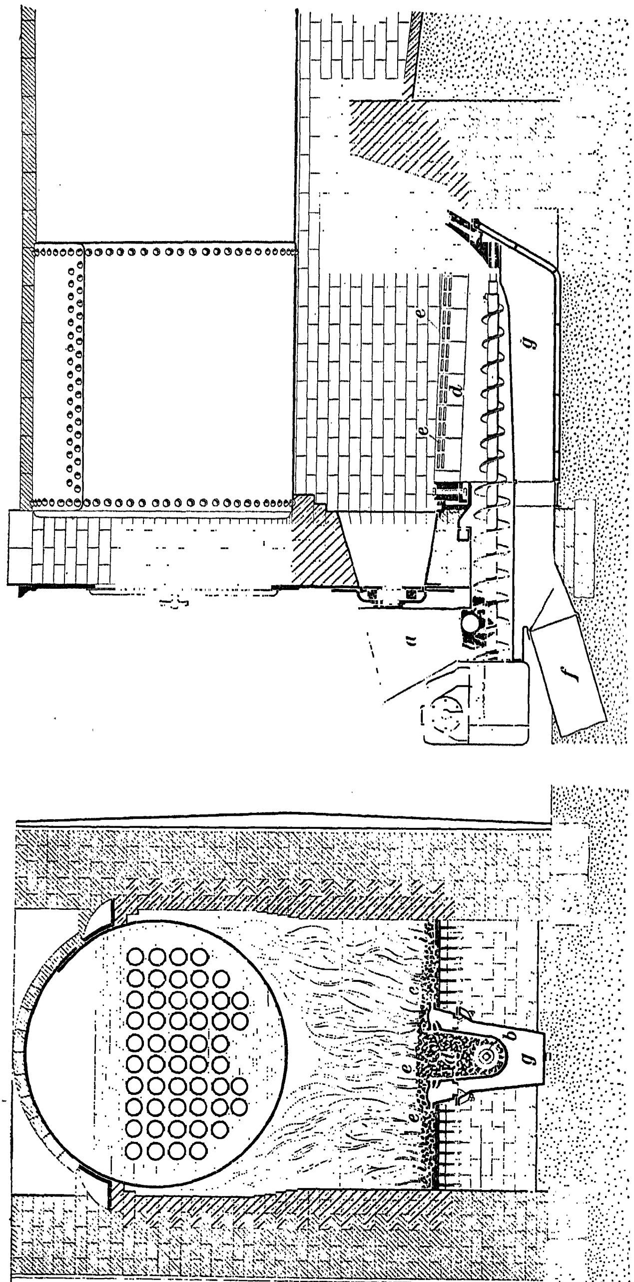


Fig. 42

magazine on to the grates *i*, where it is burned. A blower forces air through a pipe *f* into the chamber *g* surrounding the magazine. From this chamber the air passes upwards through hollow cast-iron tuyère blocks and out through the tuyères *e*. The gas formed in the magazine, mixed with the jets of air from the tuyères, rises through the burning coke above, where it is subjected to a sufficiently high temperature to insure its combustion. Nearly all the air for burning the coke is supplied through the tuyères, only a very small portion of the supply coming through the grate. The ashes and clinkers are gradually forced to the sides of the grate against the side walls of the furnace, from which they are removed from time to time through doors in the furnace front similar to the fire-doors of an ordinary furnace.

64. The construction of the American stoker is such that the fire must be cleaned and the ashes removed by hand. This has the disadvantage of a somewhat greater expenditure of labor than is required with those furnaces that discharge their ashes into the ash-pit, especially where it is desired to use ash-handling machinery; it also subjects the boiler to the deleterious influences of inrushes of cold air when the cleaning doors are opened. In this connection it may be stated that it is claimed by the makers that the fires do not need cleaning oftener than once in 8 or 10 hours with the poorer grades of coal, and that once in 12 hours is sufficient with the better grades; it is also a fact that all furnaces require occasional hand stirring and cleaning in order to secure a thoroughly satisfactory distribution of the fire on the grates and to prevent the formation of masses of clinkers that will occasionally stick to the grates, no matter how carefully the stoker is designed and operated.

CHAIN-GRATE STOKERS

65. Principle of Construction.—The chain grate, also known as the traveling grate, consists of a series of grate bars or grate-bar sections connected by hinged joints so as to form a flexible belt. It passes over sprockets or drums set at the

front and the rear of the furnace and the top travels from front to rear. The coal is fed on to the moving grate at the front and burns as it is carried toward the rear of the furnace, the ashes being dumped at the rear, where the grate turns down around the rear drum. This type of grate is extensively used in burning soft coal containing a large percentage of volatile matter; but it is also adapted to burn coal of the poorest grade, such as anthracite culm. Over the front of the grate is built a firebrick arch, which, when the furnace is in operation, reflects heat on the fresh fuel fed at the front and causes it to

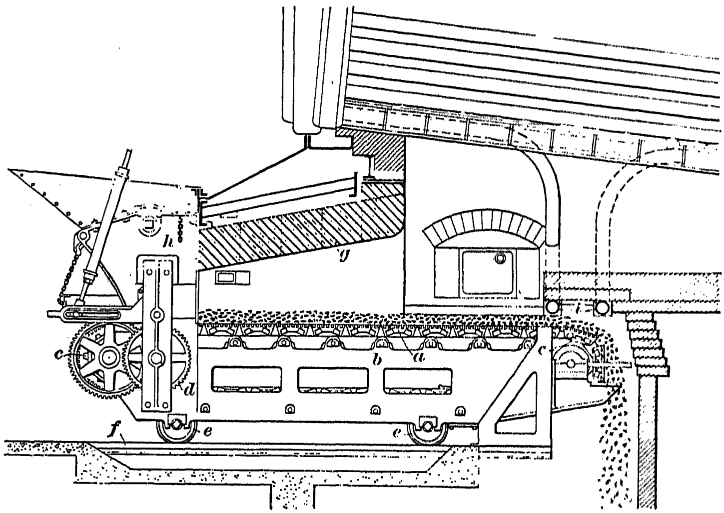


Fig. 43

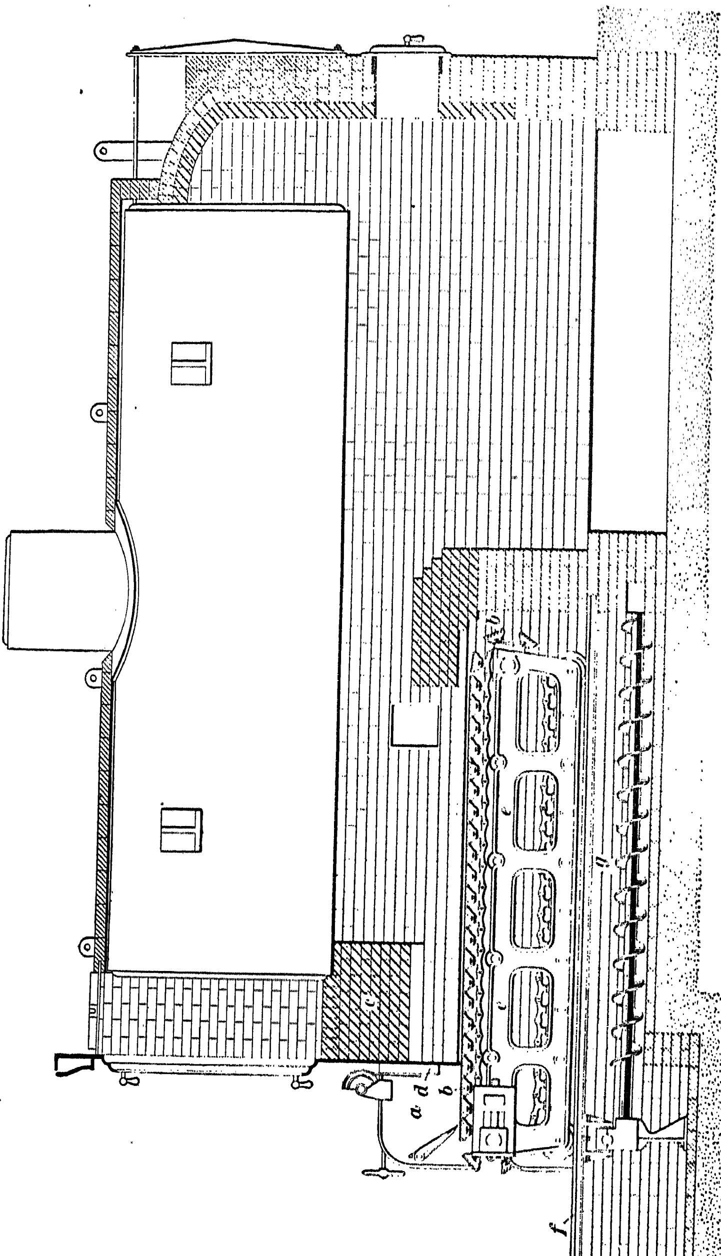
ignite. The arrangement thus becomes practically a modification of the Dutch oven. The speed at which the grate travels can be altered to suit the rate of combustion demanded by the load on the boiler.

66. Green Chain-Grate Stoker.—The stoker shown in Fig. 43 is designed for burning non-coking coal with natural draft, and is known as type K. Another form, known as type L, has an inclined apron below the fuel gate at the front, on which the fuel is fed before it reaches the grate. This type is intended for coking coal, and the volatile matter is driven off

while the fuel passes over the apron. The grate *a* consists of an endless belt built up of sections jointed together, the whole being supported by a heavy frame *b* that also carries the sprocket wheels *c* around which the grate passes. The grate receives its movement from the front sprocket wheel, which is driven by the gear *d*. This gear in turn is actuated by a pawl and ratchet connected to a shaft that is driven by an engine. The rate of travel of the grate can be varied. The frame of the stoker is carried by wheels *e* that run on the track *f*, and thus the whole stoker mechanism may be drawn out in case repairs or replacements are necessary.

67. Over the front end of the grate, Fig. 43, is a firebrick ignition arch *g*, which is so arranged as to protect the back of the hopper *h* from the heat of the furnace, and thus prevent ignition of the coal in the hopper. The arch is supported by a framework of structural steel. At the front end it is from 9 to 12 inches above the grate surface and at the rear it is from 16 to 26 inches above that surface, the distance being governed by the grade of coal and the percentage of volatile matter it contains. The bridge wall is supported by circulating tubes *i* that are connected with the water space of the boiler. The front tube forms a barrier against which the live coals at the surface of the fuel bed are carried by the rearward movement of the grate. Burning fuel is thus prevented from being carried over into the ash-pit, but the refuse is automatically dumped, as shown. The air supply to the furnace enters through the grate from the ash-pit.

68. Playford Chain Grate.—The Playford chain-grate stoker is made in two forms, known as type A and type B. Type A corresponds to standard makes of chain-grate stokers as to size and capacity, but it has its own distinctive features. Type B is of heavier construction, being made for large boiler plants and designed to operate under continuous overload conditions, if necessary. In Fig. 44 is shown a side sectional view of the chain grate as applied to a return-tubular boiler. The stoker consists of a heavy frame *e* that is provided with suitable sprocket wheels and rollers on which travels a grate *b*



made up of sections attached to endless chains. The top of the grate is driven slowly toward the rear of the furnace, taking with it coal from the hopper *a*. The amount of coal fed to the furnace is regulated by the speed of the grate and by the opening of a gate *d*, which is water-cooled to prevent the heat of the fire from igniting the coal in the hopper. The gas is distilled from the coal in the front of the furnace under the firebrick arch *c* and burns as it rises and passes toward the back. The motion of the grate carries the coke backwards at a rate that permits the carbon to be compltely burned before the rear end of the furnace is reached.

69. The ashes and clinkers from the stoker shown in Fig. 44 are dumped into the ash-pit at the back. A spiral conveyer *g* conveys the ashes from the rear of the furnace to a point near the front or to any convenient point from which they

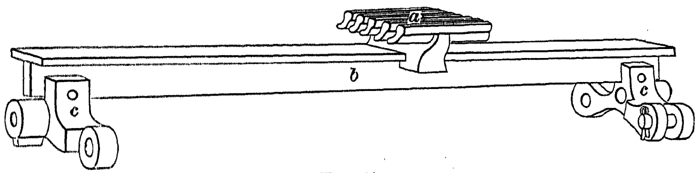


FIG. 45

can be removed. The frame *e* rests on rollers that run on rails *f* and make it possible to withdraw the stoker from the furnace when repairs are needed. In order to make the removal of burned-out grates easy and inexpensive, the grates are made in small sections, as *a*, Fig. 45, which slide over steel **T** bars *b*. The latter are in turn easily removed from the chain links *c* by taking out the pins at the ends.

The amount of power required to run the chain-grate stoker varies from 1 to $1\frac{1}{2}$ horsepower, depending on the size of the boiler. Natural draft is used for such installations and under ordinary operating conditions .15 to .30 inch of draft is sufficient. For increased capacity, from .25 to .40 inch of draft through the firebox or furnace is required. Variable loads are carried by changing the depth of fire and draft.

STOKERS FOR SMALL POWER PLANTS

70. Coal-Throwing Devices.—Stoker installations for small power plants are practically prohibited on account of the cost and lack of space needed for setting the stoker. There are devices that not only give good results in firing coal, but increase the capacity and efficiency of hand-fired furnaces and reduce the labor involved. One such form is the coal-throwing device known as the Dayton fuel feeder, shown in Fig. 46. It is

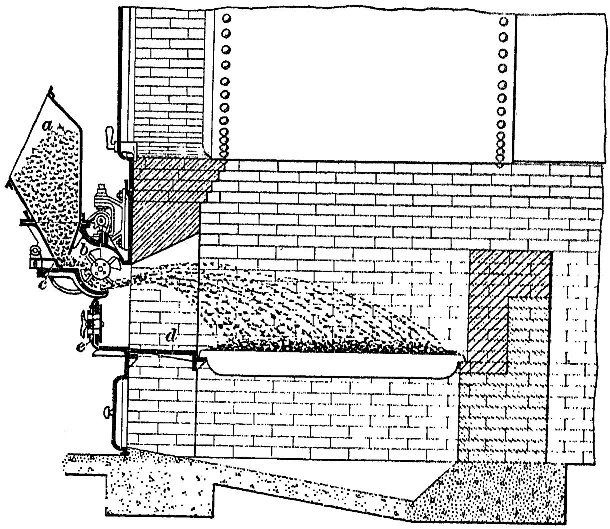


FIG. 46

arranged at the front of the boiler and, as in the larger types of stokers, a hopper feed is used. Coal is fed from the hopper *a* to a rotating wheel *b*, which delivers the coal in small amounts continuously to all parts of the grate. A pusher *c* is used to feed the coal to the wheel *b*. Whenever coal falls on the dead plate *d* it cokes and is subsequently pushed back on the grate by hand, the firing tools being inserted through the door *e*, which is also used when cleaning the fuel bed. The mechanism for driving the wheel *b* and feeding the fuel is operated by motor or steam engine and is so designed that the feed can be regulated to the required rate of combustion.

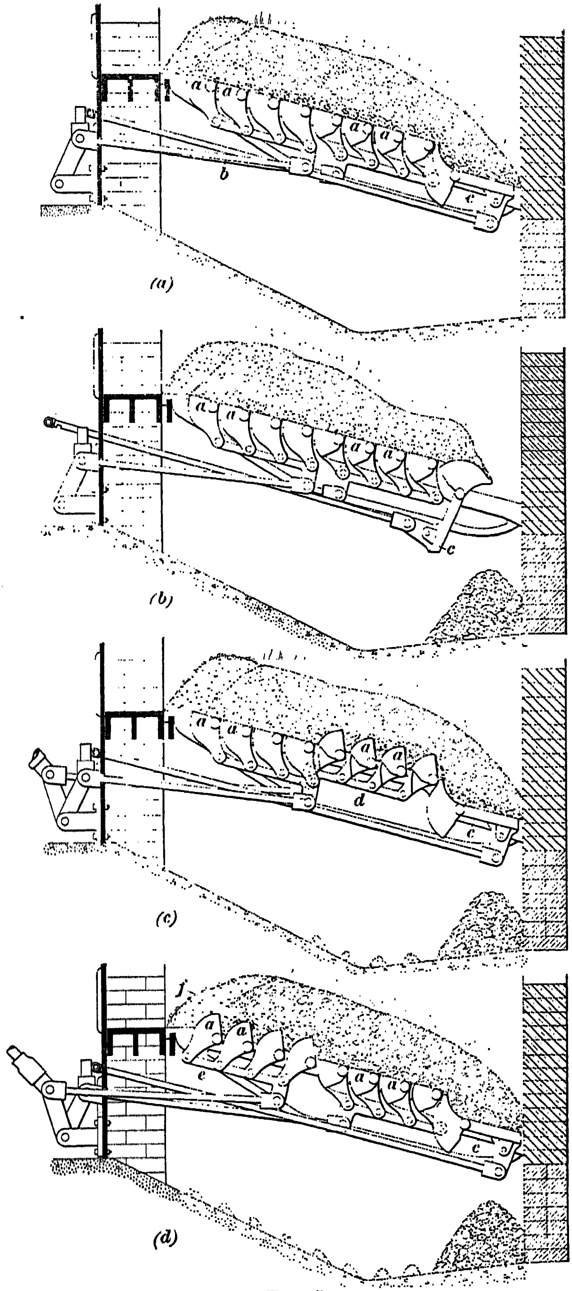


Fig. 47

71. Coal fuel feeders of the type shown in Fig. 46 handle the lowest grades of power-plant coal, which are fired to maintain a thin fuel bed. The fuel is usually fired in a moist condition, but wet coal can be fired; in such a case the fuel must be watched to see that it does not hang in the hopper. Continuous light feeding of the coal and care in keeping the fire-doors shut reduce the liability of formation of smoke and insure good conditions for combustion. In case the proper size of fuel is not available, the fuel can be fired by hand upon the dead plate *d*, and after coking it may be pushed back onto the grate.

72. Hand-Fired Stokers.—Special forms of hand-fired stokers and grates are used in small steam-power plants. A typical form of such a grate and its general features of operation are shown in Fig. 47. The grate consists of a number of grate bars *a* trunnioned at their ends and arranged to be rocked by moving the rods *b*, which are attached to levers at the front of the boiler. The grate bars are arranged in two sections that may be rocked independently, thus enabling the coal to feed toward the dump plate *c* while it is being burned. The normal condition of the fuel bed is shown in (*a*) and the first cleaning operation is shown in (*b*), in which the dump plate *c* is lowered for the removal of ash and clinker. In (*c*) the grate section *d* is operated after the dump plate *c* is closed. The grate sections *a* are raised and thrown toward the rear, thus pushing the coked coal back onto the dump plate *c*. The second stoking operation is shown in (*d*), in which the grate section *e* is operated, advancing the coked fuel onto the grate section *d*. Green coal is then thrown on the grate section *e* at the forward end of the grate, as shown at *f*. A mechanical feed from a hopper can be installed in conjunction with the hand-operated stoker. This arrangement saves considerable labor in firing the fuel and prevents excess air from entering the furnace through the open fire-doors, as occurs in hand firing. Approximately 10 pounds of fuel can be burned per square foot of grate per hour for each .1 inch of draft in the furnace. Combustion rates up to 60 pounds have been obtained, but from 30 to 40 pounds of fuel per square foot of grate per hour is general practice.

BOILER FURNACES, SETTINGS, AND CHIMNEYS
(PART 2)

BOILER SETTINGS

SETTINGS FOR BURNING OIL AND POWDERED COAL

OIL-BURNING FURNACES

1. Advantages of Oil Fuel.—Oil as fuel for stationary, marine, and locomotive boilers has come into extensive use and possesses many advantages over solid fuel. The cost of handling oil fuel is less than the cost of handling solid fuel, and as no ashes are formed, there is no problem of refuse disposal; also, the absence of dust and ashes makes oil-fuel burning far cleaner than coal burning. It is possible to obtain a more intimate mixture of oil and air than of solid fuel and air, and so an oil-burning furnace can be operated with a smaller excess of air than a coal-burning furnace, the result being that there is a more efficient use of fuel and a higher furnace temperature. With oil fuel, the steam output of the boiler can be increased more quickly than is possible with solid fuel, thus making the boiler more responsive to increases in the load.

1. The furnace walls and floor must be lined with firebrick capable of withstanding very high temperatures. There should be from .9 square foot to 1.2 square feet of firebrick surface per boiler horsepower to reflect heat and maintain uniform furnace temperature.

2. Furnace Requirements for Oil Burning.—A furnace in which oil fuel is to be burned must be designed with the following requirements in mind:

2. The furnace must be of sufficient volume to insure thorough mixing of the oil spray and the air, with proper combustion, before the resulting hot gases are permitted to strike the boiler shell or tubes. A volume of 2 cubic feet per boiler horsepower has been found to give good results.

3. The burner, or atomizing device, must be so located that the oil spray will not strike the furnace walls or the boiler surfaces; for, if it does, there is a probability that oil will drip from those surfaces when the burner is put into operation, and enough oil may collect at the bottom of the furnace to cause an explosion when the furnace walls become heated. The flame of the burning oil spray should not be localized, but should be distributed so as not to produce local stresses in or blisters on any part of the boiler.

3. Furnaces for Oil Burning.—A form of setting for burning oil fuel under a water-tube boiler of the Heine type is shown in Fig. 1 (*a*) and (*b*). It will be observed that no bridge wall or combustion arch is used; as a result, a furnace of large volume is obtained. The side walls and floor of the furnace are lined with high-grade firebrick, to withstand the high temperatures produced by oil burning. This lining, when heated to incandescence, assists in maintaining and promoting combustion. The bricks *a* in the floor just in front of the burners are laid on supports *b* made of piping and are arranged so as to leave generous spaces *c* between them, through which air enters the furnace. The quantity of air supplied is regulated by a damper in the uptake and by doors at the front of the furnace. Baffles *d* of refractory tile are provided to lengthen the gas travel over the tubes. The burners *e* are set in openings *f* in the front wall of the furnace, and the oil is sprayed toward the rear of the boiler by either steam or air. This arrangement gives the burner the name of *front-shot burner*.

A Stirling boiler arranged for oil burning is shown in Fig. 2 (*a*) and (*b*). The sectional view (*a*) is taken transversely

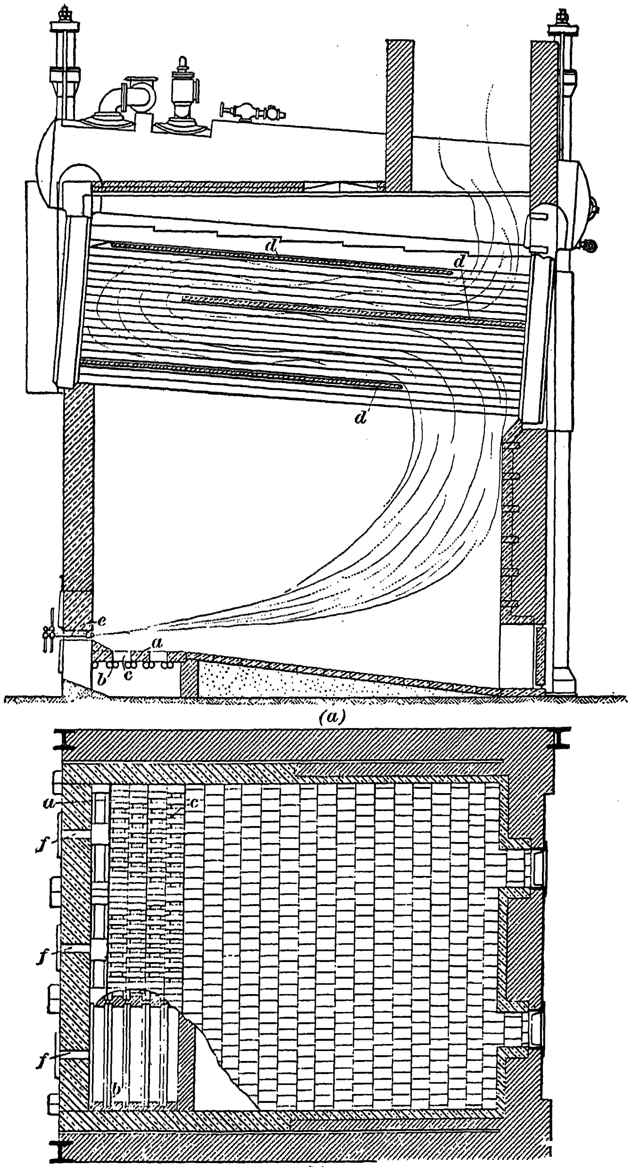


FIG. 1

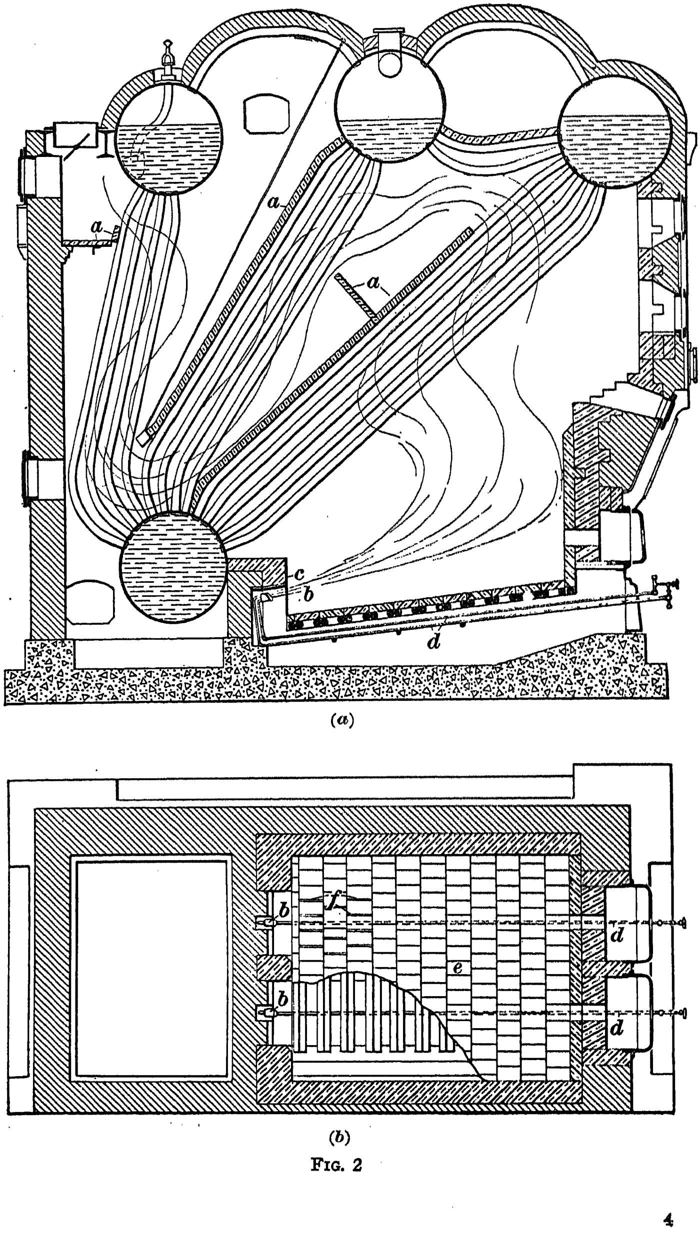


FIG. 2

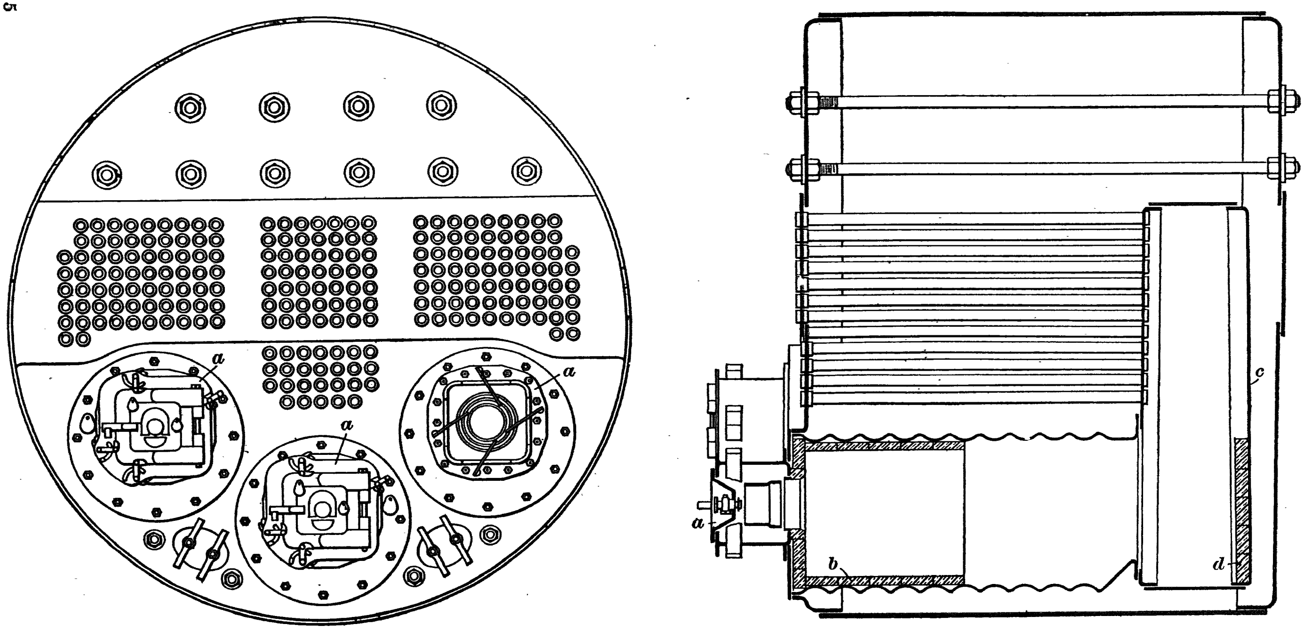


FIG. 3

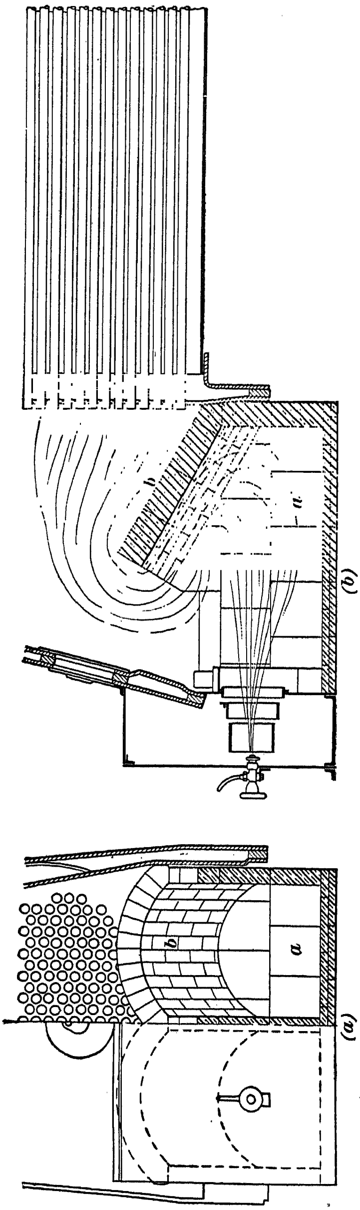


FIG. 4

through the drums of the boiler to indicate the position of the baffles *a* and the oil burners *b*. The burners, which are termed *rear-shot burners,* are placed at the back of the furnace, and as the firing is from the rear to the front, the gases travel forwards and then back under the front baffle *a*. When the burner is so placed it must be protected from the furnace heat. For this purpose a housing *c* of brick is set around it. The piping *d* to the burner is placed under the furnace floor *e*. The air is admitted into the furnace through openings in the floor *e*, and air slots *f* are allowed between the bricks in front of the burners *b* to prevent the formation of soot, which would form on the floor and fuse with the brick.

4. Oil Furnace for Scotch Boiler.—For burning oil in an internally fired boiler of the Scotch type, as in Fig. 3, the burners *a* are placed at the front of the corrugated furnaces. To protect the mouth of the furnace against the intense heat, a firebrick lining is built around the burner setting and back into the furnace to a distance of about one-half

the furnace length, as indicated at b. The rear plate c of the combustion chamber is also protected by a firebrick wall d, which is called a *target wall*, or *flash wall*. This wall forms a retainer of heat, as it becomes incandescent after the fire has been in operation for a time. When the oil spray strikes the wall, it flashes immediately into flame.

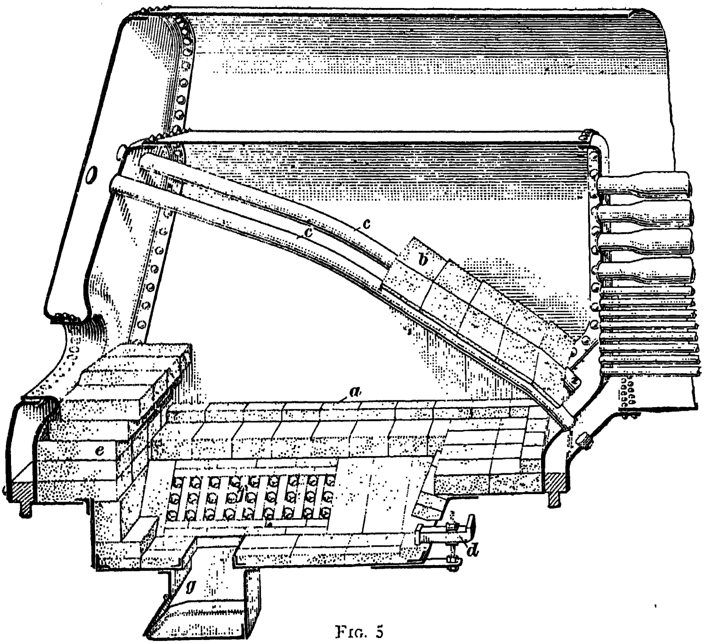


FIG. 5

5. Oil Furnace for Locomotive Boiler.—The firebox of a locomotive-type boiler burning oil fuel is also lined with firebrick, which is built up along the sides of the firebox to provide a target wall and an arch. A combustion arch is essential, as otherwise the gases would pass out directly into the tubes only partly consumed. The combustion arch promotes a more intimate mixture of the gases and air and maintains a more nearly uniform furnace temperature. Fig. 4 (a) and (b) illustrates a method of constructing the walls a and combustion arch b for firing oil from the front. In order to obtain sufficient fur-

nace volume with some types of firebox boilers, it is necessary to set the firebrick walls and floor well below the crown sheet. Doing this may necessitate building part of the brickwork outside the firebox, as shown in the illustration. The furnace illustrated is arranged for two burners, each of which has its own combustion arch.

Another form of arrangement is shown in Fig. 5. The lower part of the firebox is lined with firebrick *a*, and the arch bricks *b*

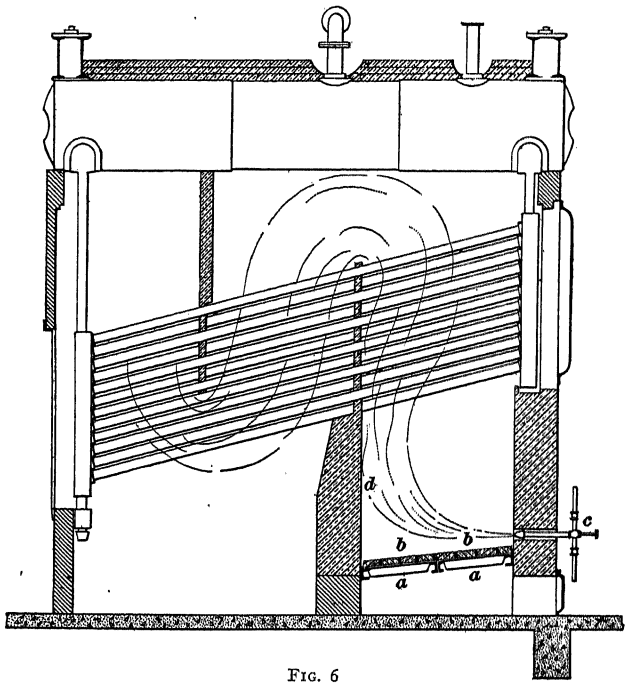


FIG. 6

are supported by the arch tubes *c*. The burner is located at *d*, so that the flames are directed against the target wall *e*. Air is admitted through the holes *f*, as well as through the hopper door *g* when it is opened.

6. Adapting Coal-Burning Furnaces for Oil Burning.—A boiler setting intended for the use of coal as fuel may be adapted to oil burning with little change, and in case of necessity

it may be reconverted to a coal-burning furnace with little delay. The grate bars usually need not be removed, but firebrick must be laid on them, with proper openings to admit air beneath the burners. If a large combustion space must be obtained, the grates may be taken out and the floor of the ash-pit arranged as in Fig. 1 or Fig. 2. In the setting shown in Fig. 6, the grates *a* are left in place and are covered with a layer of firebrick *b*. A front-shot oil burner *c* is installed in the front of the furnace and the flames are projected against the bridge wall *d*. Baffles across the tubes cause the hot gases to follow the course indicated. It will be observed that the upper front ends of the tubes are not in the direct path of the hot gases, which is a disadvantage. The use of a rear-shot burner would overcome this and would probably result in a better distribution of heat.

EQUIPMENT FOR BURNING POWDERED COAL

7. Preparation of Powdered Coal.—Furnaces used in the cement industry and in various metallurgical processes have long been burning powdered coal as fuel with great success; but the application of such fuel to the firing of steam boilers is of more recent adoption. To bring the coal to the desired condition, it must be put through a number of processes involving crushing, drying and powdering, for which special machinery is required. A typical system for producing powdered coal is illustrated in Fig. 7 (*a*) and (*b*). The lump coal is dumped from the railroad cars into a bin *a* beneath the track, from which it is lifted by a bucket elevator to the crushing rolls *b*, where it is broken into pieces small enough to dry readily. It then descends by gravity to the feeder *c*, which feeds it into the upper end of the dryer *d*. The dryer is a long cylinder that is inclined slightly from the horizontal and is rotated by suitable gearing. It passes through the combustion chamber of a furnace *e* and so is heated externally. At the same time, the hot gases from the furnace are led by the pipe *f* to the hood *g* enclosing the lower end of the dryer, from which they flow through the dryer and escape to a stack at its upper end. Inside the dryer are longitudinal shelves, so that, as the dryer rotates,

the coal is picked up, carried part way round, and dropped off the shelves, while at the same time it is acted on by the current of hot gases passing through the dryer and the heat transmitted

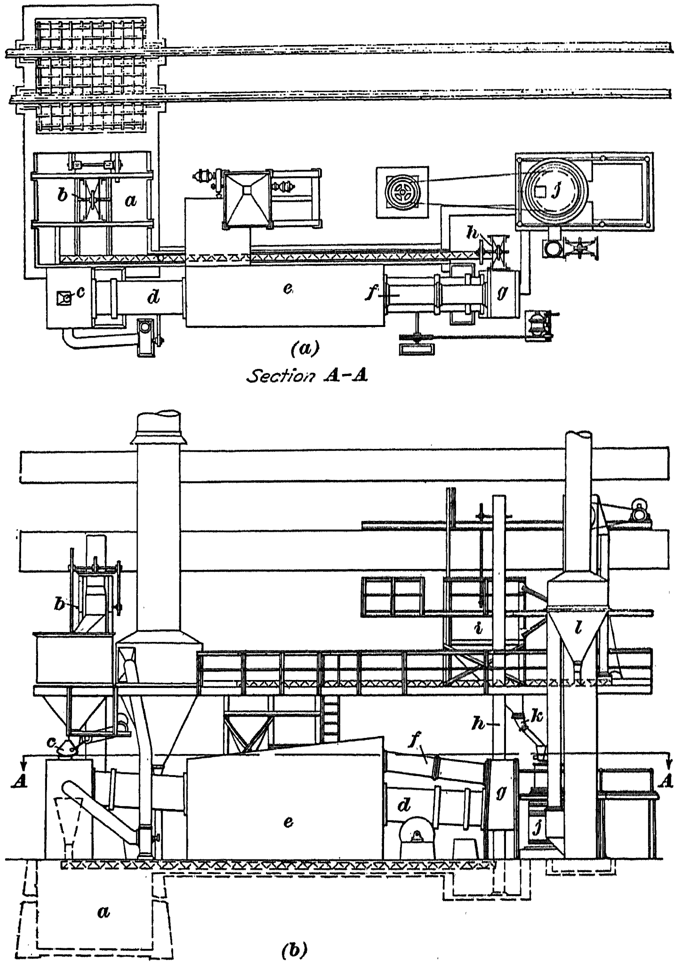


FIG. 7

through the shell of the dryer. As the dryer is inclined, the coal gradually works down to the lower end, where it is picked up by an elevator *h* and carried into a storage bin *i*.

8. Before the dried coal is discharged into the storage bin *i*, Fig. 7, it passes over a magnetic pulley that catches all iron that may have accidentally found its way into the crushed coal. These pieces of iron, if allowed to remain, would interfere with the working of the crushing mill, or pulverizer *j*, into which the dried coal is fed through the gate *k* and its connecting pipe. Here it is ground to a powder of such fineness that at least 95 per cent. of it will pass through a 100-mesh screen, which means a screen having 10,000 openings to the square inch. During the pulverizing, coal dust is formed, which is drawn into the dust collector *l* and caught, instead of being allowed to go to waste. The pulverized coal is delivered to the boilers by suitable conveyers and is ready for use without further treatment. The coal crusher, elevators, dryer, and pulverizer are driven by electric motors. Coal of any kind can be powdered and burned, regardless of the ash it contains; but the higher the fusing point of the ash, the better will be the operating conditions, as an ash with a low melting point is likely to form a slag on the furnace walls, whereas an ash of high melting point will be deposited as dust.

9. Burning Pulverized Coal.—One form of equipment for burning pulverized coal, as applied to a Stirling boiler, is shown in Fig. 8. The powdered coal is contained in the bin *a*, to which it is brought from the pulverizers by the screw conveyer *b*. The bin is elevated, so that the fuel may be supplied to the burner by gravity and also to leave ample room around the boiler setting for making repairs. The powdered coal descends from the bin into the coal feeder *c*, which is a cylindrical casing containing a spiral conveyer driven by chain gearing from the motor *d*. A slide or gate at the bottom of the bin enables the fuel supply to be shut off completely, if that becomes necessary. The motor *d* is of the variable-speed type, so that the rate at which the feeder *c* operates may be adjusted to the load on the boiler and to the demand for fuel. From the feeder the powdered coal falls through the pipe *e* into the burner *f*, where it is met by a blast of air supplied through the pipe *g* from the blower *h* and driven into the furnace, where it burns.

Additional air for combustion enters through the adjustable register *i*, the damper-controlled ducts *j*, and the shutters in the ash-pit doors *k*.

10. Furnace Design for Burning Powdered Coal.—The furnace for burning powdered coal must be of such proportions that the fuel will be burned before the resulting hot gases touch

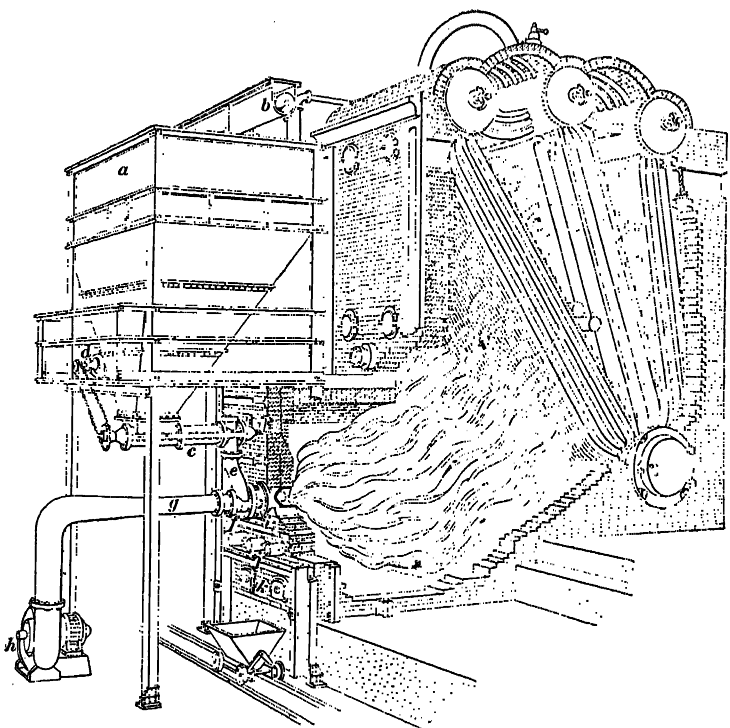


FIG. 8

the boiler surfaces. For bituminous coals high in volatile matter, the volume of the furnace may be satisfactorily taken as 2 to $2\frac{1}{2}$ cubic feet for each boiler horsepower. The interior of the furnace should be made in the form of a cube, if possible, with the side walls sloping inwards toward the ash-pit, so that the dust and slag will slide easily into it. Furnaces are sometimes extended in the form of a Dutch oven to provide addi-

tional space for the combustion of the fuel. The firebrick walls should be made heavy and of high heat-resisting quality, as high temperatures and gas velocities are developed in burning this fuel. These conditions in combination with the erosive action of the dust and slag cause the brick to waste away.

RECLAIMING WASTE HEAT

11. Utilizing Waste Gases From Kilns.—In the various processes involved in the manufacture of iron, steel, and cement, heat is used, and the hot gases coming from the furnaces and kilns contain much heat that may be utilized instead of being allowed to go to waste. The temperature of these so-called waste gases may be from 1,000° to 1,600° F., and much of their heat may be reclaimed by passing them through specially designed boiler settings. In a direct-fired furnace, the temperature may range from 2,000° to 3,000° F. As a waste-heat installation has to deal with temperatures only about half as high as these, the problem of design is quite different, as the heat transmitted per square foot of boiler heating surface is much less at the lower temperatures. In early waste-heat installations, 20 square feet of heating surface was allowed for each boiler horsepower to be developed, and as a result, both the boilers and their settings were very large.

Experience showed that the rate at which heat was transmitted from hot gases to water inside a boiler was increased by increasing the speed with which the gases swept over the heating surfaces, and this fact was used as a means of reducing the size of waste-heat installations. The waste gases were given higher velocities in moving over the boiler surfaces, and thus smaller boilers could be used with no reduction of capacity. At present, the hot gases in waste-heat installations move at such a rate that from 2,500 to 4,500 pounds of gases pass through the boiler setting per hour per square foot of area of gas passage. Water-tube boilers are extensively used. The waste gases from cement kilns carry much dust, and so a boiler with horizontal baffles should not be used for such gases, as the dust would collect on them and eventually choke the gas passages.

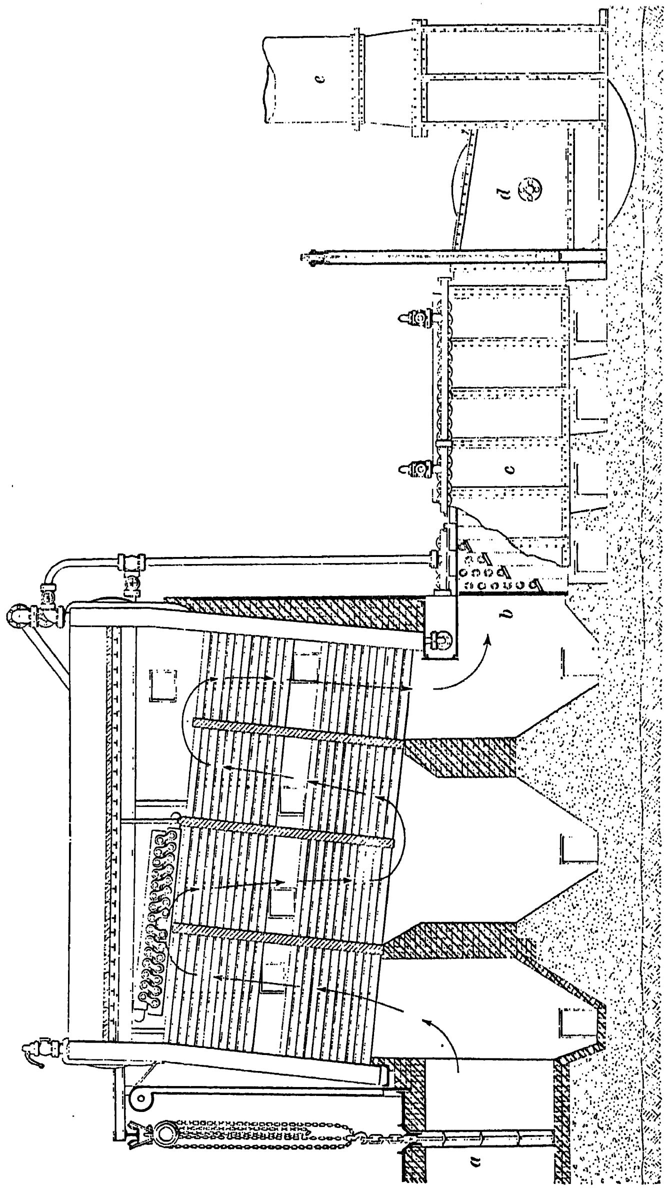


FIG. 9

12. A typical waste-heat installation is shown in Fig. 9. The water-tube boiler is set high and the tubes are longer than in the type of boiler used with a direct-fired furnace. Vertical baffles give four passes of the hot gases over the tubes. The waste gases enter at *a*, follow the course indicated by the arrows, and escape at *b* into an economizer *c*, where they give up further heat to the feedwater. A fan *d* in the passage leading to the stack *e* draws the gases through the boiler setting at the desired speed. The speed of the fan may be varied by driving it from a steam turbine or a variable-speed motor. As the fan creates a suction through the economizer and the boiler, there is a partial vacuum inside the boiler setting, and the danger of air leakage through the setting and the clean-out doors is thereby increased. The clean-out doors should be fitted with gaskets to make them air-tight.

13. Preheating Air by Flue Gases.—One of the large losses of heat in boiler operation arises through the escape of flue gases at a high temperature. To recover a part of the heat thus leaving the boiler, a feedwater economizer may be set in the path of the flue gases. Still another way of accomplishing the same end is to utilize the heat of the flue gases to preheat the air supplied to the furnace. An apparatus constructed for this purpose is shown in Fig. 10, in which (*a*) is a general view, partly in section. The middle section *a* encloses a rotating heating element *b*, shown in detail in view (*b*), made up of alternate series of flat and corrugated plates bent to cylindrical form, and driven by chain gearing from the shaft *c* that carries the fans *d* and *e*. The fan *d* forces the cool fresh air into the upper section *f*, which is fitted with a partition *g* that deflects the air downwards through the rotating element *b* into the lower section *h*. The partition *i* compels the heated air to pass down into the flue *j* that leads to the furnace of the boiler. The interior of the lower section is shown clearly in view (*c*).

14. The escaping flue gases from the boiler are led to the preheater, Fig. 10 (*a*), by the flue *k*, and discharged into the lower section *h*, the fan *e* acting as an exhauster to keep the gases in motion. The baffle plate *l* compels the hot gases to

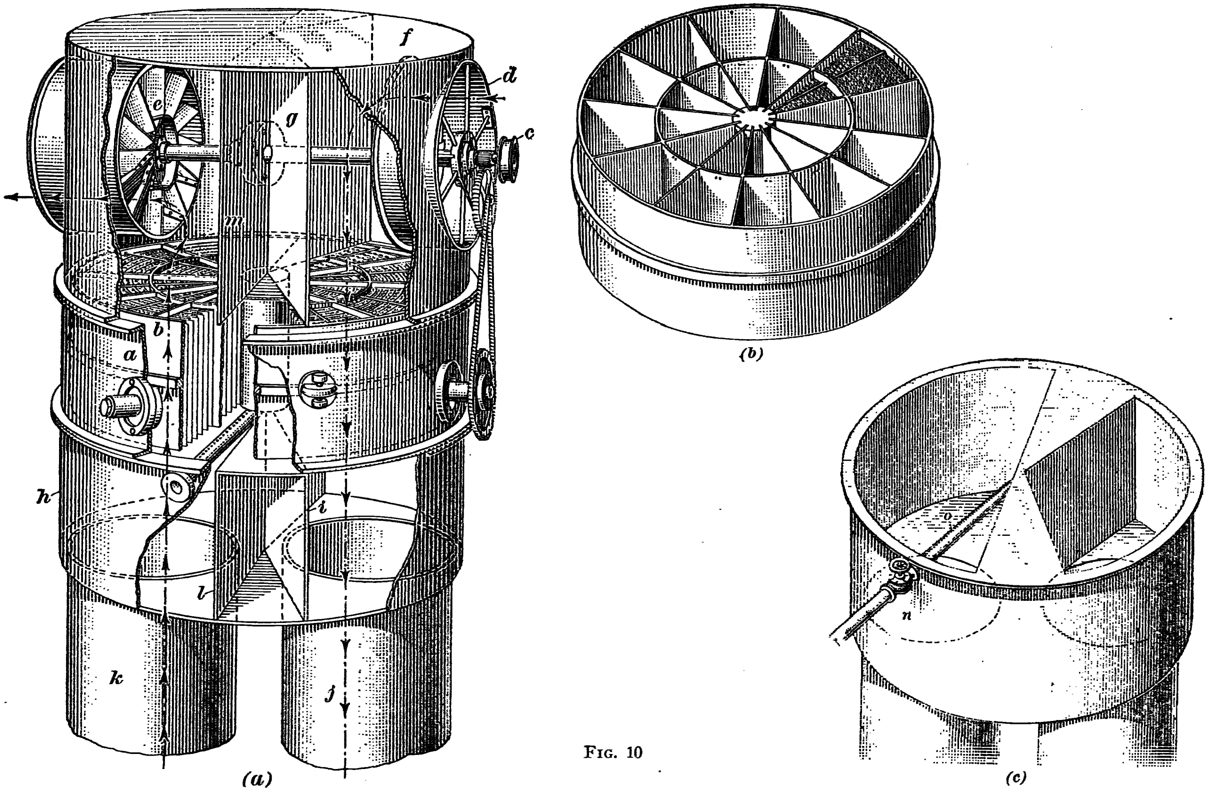


Fig. 10

rise through the left half of the rotating element *b*, to which they give up their heat. They then pass into the upper section *f*, are deflected by the partition *m*, and are forced out to the chimney by the fan *e*. Thus, there is a steady flow of fresh air down one side of the device and a similar flow of hot flue gases up the other side. The rotating element *b* absorbs heat from the flue gases, and, after rotating into the path of the fresh air, gives up the heat to the fresh air. Thus, there is a continuous transfer of heat from the flue gases to the air supply without mixture of the two currents, the rotating element *b* serving to transfer the heat. The effect of preheating the air supply in this manner is to increase the efficiency of combustion and at the same time to recover heat that would otherwise go to waste. The valve *n*, view (*c*), admits steam to the perforated pipe *o* that acts as a soot blower to clean the plates of the rotating element.

CHIMNEYS AND DRAFT

HANDLING FLUE GASES

BREECHINGS

15. Forms of Breechings.—The breeching forms the connection between the smoke outlet of the boiler and the chimney. Its shape depends on the type and number of boilers in the installation and whether they are stationary or marine. A common form of breeching for a stationary boiler is shown in Fig. 11 (*a*). The base *a*, which is connected to the smoke outlet of the boiler, is rectangular in shape, whereas the top *b*, to which the stack is fastened, is circular, the two being joined by the tapering body *c*. If two boilers are to be connected to the same stack, the form of breeching shown in (*b*), known as a **Y** breeching, is used. The bases *a* and *b* are connected to the smoke outlets of the boilers and the stack is connected at *c*. To prevent collision and eddying of the gases flowing from the

two branches *d* and *e*, it is customary to provide a separating plate, or baffle, at the throat where the two branches unite.

16. In case a breeching must serve a battery of boilers, it is made tapering in form, so that its cross-sectional area

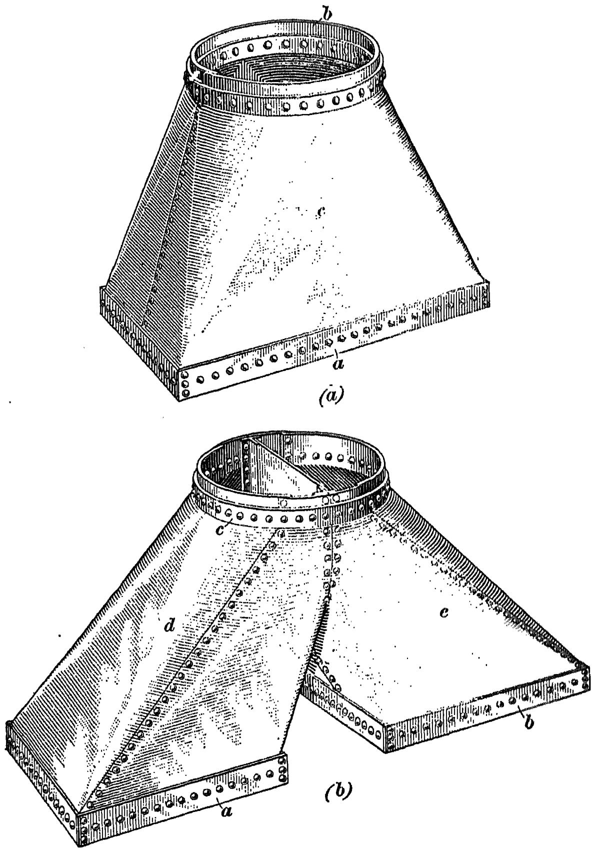


FIG. 11

increases toward the stack and thus accommodates the greater quantity of gases. Such a breeching is shown in Fig. 12. The sides are straight, flat surfaces and the top is arched. The bottom is flat, and in it are the openings *a* through which the gases from the boilers enter the breeching.

17. The form of breeching used on a Scotch boiler is shown in Fig. 13. It is attached to the front of the boiler and is of such shape as to cover the ends of the tubes and leave the space in front of the furnaces unobstructed. Its taper is such that the area of the passage increases toward the top, where it joins the uptake. Doors *a* are provided so that access may be obtained to the tube-sheet for cleaning and repairing tubes. Clean-out doors must also be provided at the bottom of the breeching, to facilitate the removal of dust and soot carried

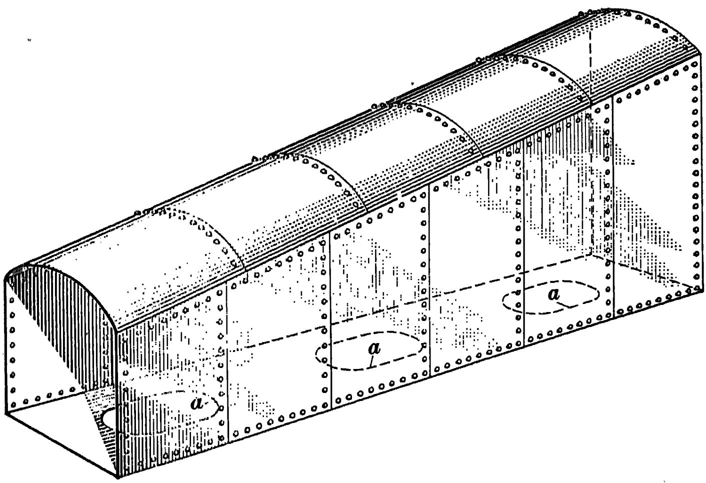


FIG. 12

through the tubes and deposited in the breeching. Breechings are made of steel plate about $\frac{3}{16}$ inch thick.

18. Breeching Design.—Breechings and their connections to the stack should be so designed as to offer the least possible resistance to the flow of gases. Straight connections with angular bends, as shown in Fig. 14 (*a*), hinder the gas currents, as the corners *a* cause eddies to form, as shown by the shaded area. To overcome this, the entrance to the smoke outlet should be rounded, as shown in (*b*), by the use of elbows. A round elbow and breeching will cause less draft loss than a square or rectangular type with curved top or bottom. The

cross-sectional area of the breeching should be made larger than that of the stack. In general practice the cross-sectional area is made from 10 to 25 per cent. larger than the cross-sec

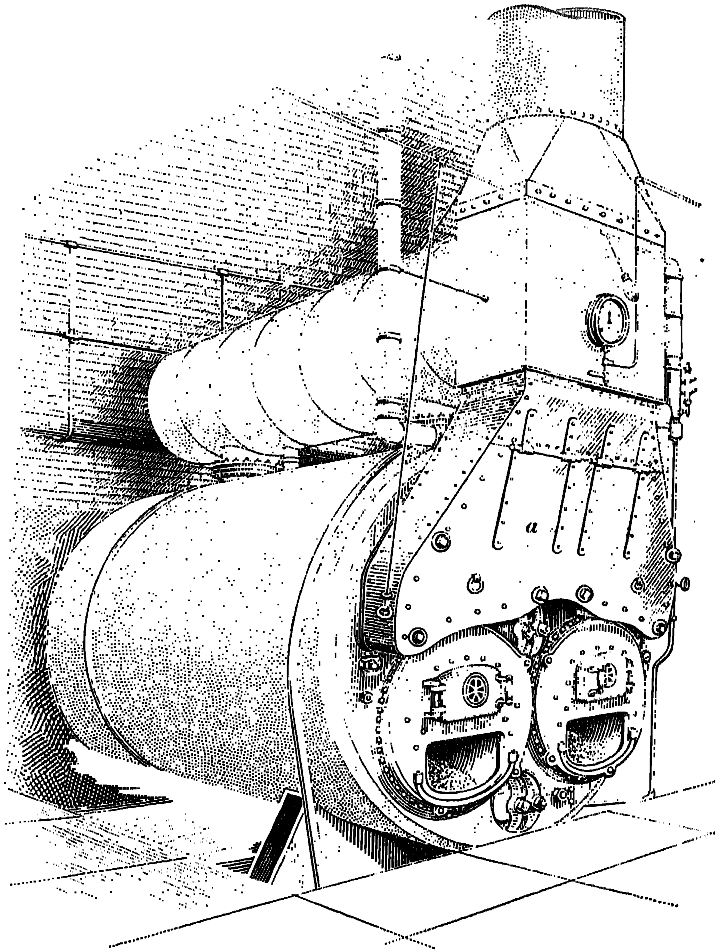
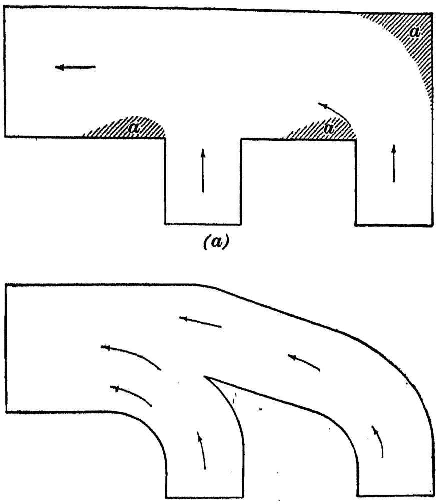


Fig. 13

tional area of the stack, depending on the nature of the fuel to be burned and the amount of flue dust expected. Builders of chimneys prefer to make the area of the flue opening from 7 to 10 per cent. larger than the cross-sectional area of the stack.

TYPES OF CHIMNEYS

19. Details of Construction.—Chimneys are usually built of brick, though concrete, iron, and steel are often used for those of moderate height. Brick chimneys are usually built with a flue having parallel sides and a taper on the outside of the chimney of from $\frac{1}{16}$ to $\frac{1}{4}$ inch per foot of height. The external diameter at the base of a brick chimney should be made about one-tenth of its height to insure stability. The thickness of the outer wall is usually one brick, or about 8 or 9 inches, for the first 25 feet from the top, increasing one-half bricks for each additional 25 feet from the top downwards. If the inside diameter exceeds 5 feet, the top should be one and one-half bricks thick; if less than 3 feet in diameter, it may be one-half brick in thickness for the first 10 feet from the top.



(a)
(b)
Fig. 14

20. A round chimney gives greater draft area for the same amount of material in its structure and exposes less surface to the wind than a square chimney. Large brick stacks are usually made with an inner core and an outer shell, with a space between them. The core is free to expand with the heat without distorting the shell. Sometimes the shell has iron rings laid up in the brickwork every 4 to 5 feet. Large brick chimneys are usually constructed with a series of internal pilasters, or vertical ribs, to give rigidity. The top of the chimney should be protected by a coping of stone or a cast-

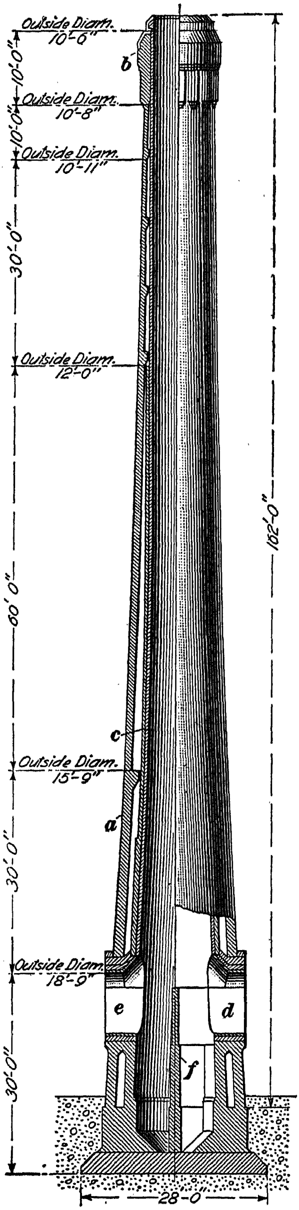


FIG. 15

iron plate to prevent the destruction of the bricks by the weather; some ornamental finish is usually added at the top of the chimney.

21. Iron or steel stacks are made of plates varying from $\frac{1}{8}$ to $\frac{1}{2}$ inch thick. The larger stacks are made in sections, the plates being about $\frac{1}{4}$ inch thick at the top and increasing to $\frac{1}{2}$ inch at the bottom; they are lined with firebrick about 18 inches thick at the bottom and 4 inches at the top. Some designers prefer to use no lining on account of the likelihood of corrosion and the difficulty of inspection, and also because the inside of lined stacks cannot be painted.

On account of the great concentration of weight, the foundation for a chimney should be carefully designed. Good natural earth will support from 2,000 to 4,000 pounds per square foot. The footing beneath the chimney should be made of large area. In compressible soils, piles should support the footing.

22. Brick Chimney.—A brick chimney 162 feet high is shown in Fig. 15. The flue is 12 feet 3 inches in diameter at the base, tapers to 8 feet half way up, and remains of the same size to the top. The outer wall *a* is 17½ inches thick for the first 50 feet, 13 inches for 60 feet, and 9 inches thick to the ornamental top *b*. The core *c* is 13½ inches thick for 20

feet above the flue openings, 9 inches for the next 70 feet, and $4\frac{1}{2}$ inches for the remainder. There are two flue openings *d* and *e* with a deflecting partition *f* extending about two-thirds of their height between them.

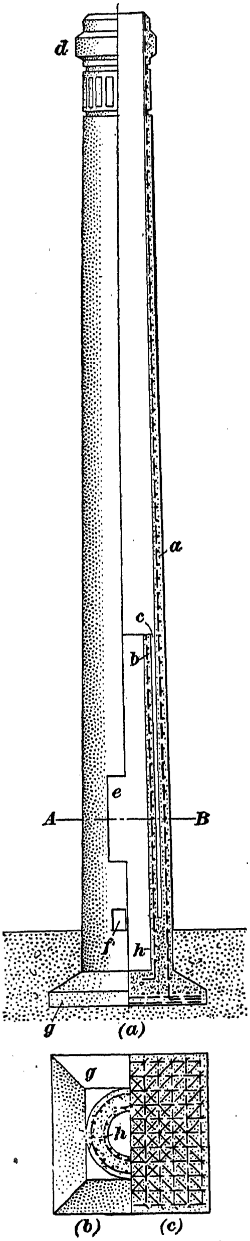
23. Reinforced-Concrete Chimney.—Reinforced concrete is especially adapted for constructing chimneys that are to be located where foundation soils are not good, because its comparatively light weight permits the use of lighter and less expensive foundations than for any other kind of permanent chimney. Since a reinforced-concrete chimney is used as a conduit for hot gases, its heat-resisting properties are of paramount importance. Engineers have not reached definite agreement as to the best construction to use within the chimney; some insist upon a lining of firebrick for at least the lower portion; others use a lining of concrete for the entire height or for a portion only; and some use a single shell of concrete, which in some cases has been left unprotected and in other cases has been encased in special clay tile.

There are at present in common use two principal designs of reinforced-concrete chimney, known respectively as the *Weber chimney* and the *Wiederholdt chimney,* both of which are patented. The Weber chimney is entirely of reinforced concrete, while the Wiederholdt chimney is of reinforced concrete encased in tile.

24. The Weber chimney may be either cylindrical, or tapered, but the cylindrical form is not often built now. The tapered, or coniform, chimney is constructed as shown in Fig. 16, in which (*a*) is an elevation with a portion removed to show the construction; (*b*) is a half plan of the footing; (*c*) a half section showing the reinforcement of the footing, and (*d*) an enlarged section on the line *A B* of view (*a*). The chimney has an outer shell *a* reinforced to withstand the force of the wind; its thickness and reinforcement depend on the locality and on the height and diameter of the chimney. Within this shell is a 4-inch shell *b,* also of reinforced concrete; this shell withstands the heat of the gases and extends up far enough

for the gases to be somewhat cooled before coming in contact with the outer shell. Between the shells is an air space *c* that prevents the heat from penetrating to the outer shell. Since concrete expands under heat this space also permits the inner shell to expand as required.

25. At the top of the chimney, Fig. 16, is an ornamental cap *d* consisting of a heavy ring of concrete with extra reinforcement to stiffen the concrete at the top. Some distance above the ground is the flue opening *e* through which the gases are admitted to the chimney. The concrete immediately surrounding the flue opening is reinforced with extra steel rods and thickened by the omission of the air space at this place, as plainly shown in (*d*). Below ground is the footing *g*, consisting of a tapered block of reinforced concrete constructed as shown in (*b*) and reinforced as indicated in (*c*). The wall of the chimney is solid below grades, as shown at *h* in views (*a*) and (*b*).



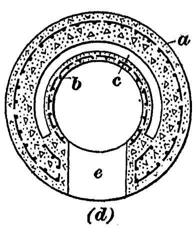


FIG. 16

26. The Wiederholdt chimney, Fig. 17, differs from the Weber chimney in being built without molds, the wall consisting of **H**-shaped tiles of the shape shown in Fig. 18. These tiles are laid up first to form a hollow wall into which

the concrete is poured. The tiles permit of the installation of the vertical and horizontal rods that are required. The arrangement of steel shown in Fig. 17 is typical of all reinforced-concrete chimneys. The main reinforcing rods *a* extend vertically the entire height of the chimney and at their lower ends serve to tie the chimney to the footing block *b* so as to prevent

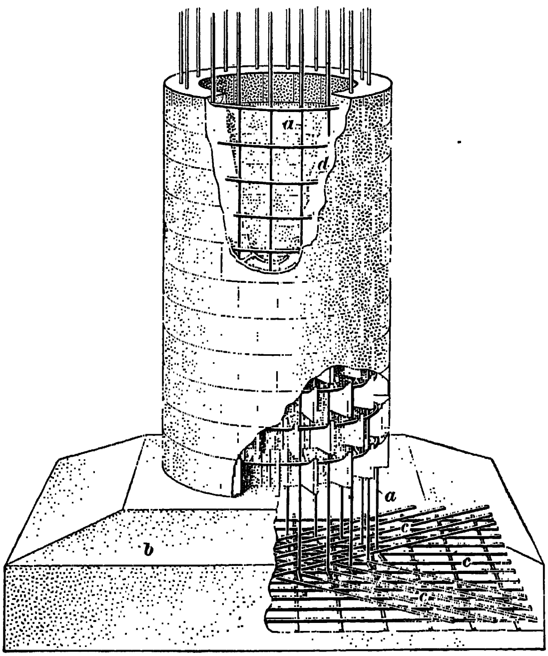


FIG. 17

the chimney from blowing over, because in the footing the rods *a* interlock with the footing rods *c*, of which there are four layers. At intervals throughout the height, horizontal rings *d* surround the vertical rods; these horizontal rings consist of lighter rods than the vertical and are often ½-inch round rods 14 inches apart. In order to permit these rods to pass through the tiles, the partition *a*, Fig. 18, is notched, leaving an open space *b* for the passage of the rods.

27. Steel Chimney.—A self-supporting steel chimney is shown in Fig. 19. It is 225 feet high above the foundation, and the inside diameter of the shell is 14 feet 8 inches at the top and 17 feet at the top of the flare at the base, and the inside diameter of the lining is 13 feet 9 inches. It is set on a foundation about 16 feet high, built of dimension stone laid in Portland-cement mortar. (*Dimension,* or *cut, stones* are stones that have been cut to dimensions in advance of laying.) The chimney is composed of a number of rings made of plates 4 feet high by about 6 feet long and $\frac{1}{4}$ inch thick for the first 40 feet from the top, increasing in thickness by $\frac{1}{32}$ inch per 40 feet for 160 feet. The first 25 feet at the bottom is made of $\frac{7}{16}$-inch plates cut to such shape that when riveted together they form a bell-shaped section that flares from 17 feet in diameter at the upper end to 27 feet in diameter at the foundation-bolt circle at the base. Vertical anchor bolts hold the chimney to the foundation and prevent it from blowing over. The chimney has a firebrick lining ranging in thickness from 18 inches

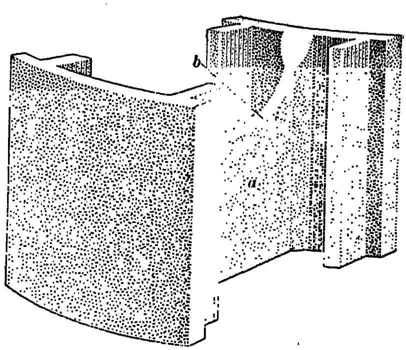


FIG. 18

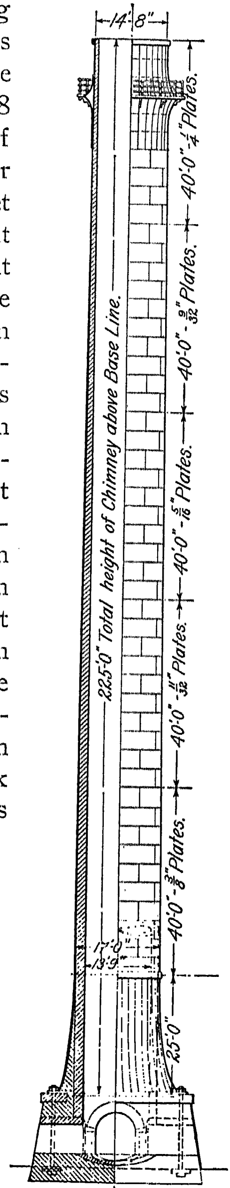
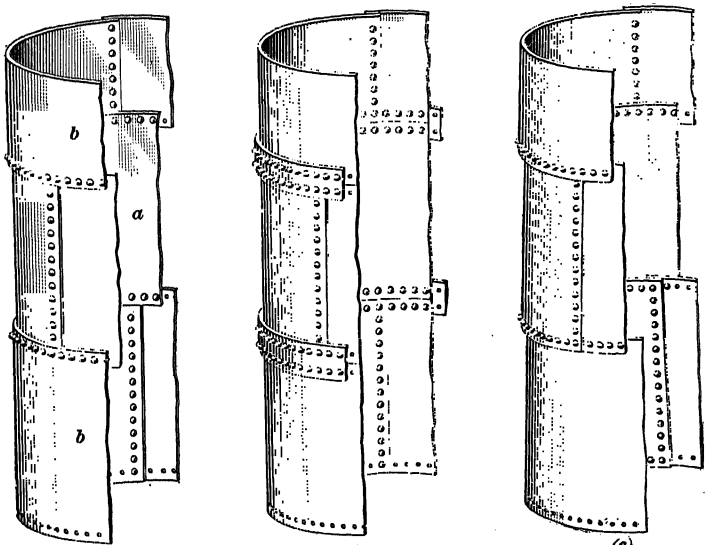


FIG. 19

at the bottom to 4½ inches at the top. Four smoke flues, one on each side, enter the foundation near the bottom.

28. Guyed Steel Stacks.—Stacks made of light sheet iron are neither so high nor so large in diameter as self-supporting steel chimneys and consequently do not require heavy foundations. Stability, or resistance to overturning under the effect of wind pressure, is obtained by running guy wires from the upper part of the stack to anchors or suitable fastenings at the ground



(a) (b) (c)

FIG. 20

level or on adjoining buildings. The stack is usually built of a series of cylindrical rings riveted together, as shown in Fig. 20 (*a*), alternate sections *a* being made of such diameter as to fit inside the adjacent sections *b*. The rivets in the circumferential seams have a pitch of about 3 inches, and those in the vertical seams a pitch of 3 to 4 inches. Another form of construction, shown in (*b*), makes use of sections of the same diameter, which are butted together and joined by butt straps riveted on the outside, though they may be put on the inside.

Outside straps are preferable, as the inside of the stack then has a uniform diameter throughout, with nothing to interfere with the flow of the gases.

29. In the stack construction shown in Fig. 20 (*c*), the sections are tapered, the upper end of each being slightly smaller in diameter than the bottom. The top of each section then fits into the bottom of the section next above, and the

TABLE I

PLATE THICKNESSES AND RIVET DIAMETERS FOR GUYED STACKS

Diameter of Stack Inches	Thickness of Plate Minimum U. S. Standard Gauge	Diameter of Rivet Inch	Thickness of Plate Maximum Inch	Diameter of Rivet Inch
30	10	$\frac{3}{8}$	8 (gauge)	$\frac{3}{8}$
36	10	$\frac{3}{8}$	$\frac{3}{16}$	$\frac{7}{16}$
40	10	$\frac{3}{8}$	$\frac{1}{4}$	$\frac{7}{16}$ or $\frac{1}{2}$
48	8	$\frac{3}{8}$	$\frac{1}{4}$	$\frac{7}{16}$ or $\frac{1}{2}$
54	$\frac{3}{16}$ in.	$\frac{7}{16}$	$\frac{5}{16}$	$\frac{1}{2}$ or $\frac{5}{8}$
60	$\frac{3}{16}$ in.	$\frac{7}{16}$	$\frac{5}{16}$	$\frac{1}{2}$ or $\frac{5}{8}$

two are riveted together. The lap on the outside thus faces down, and so does not form a ledge on which moisture can collect.

The plate thicknesses and diameters of rivets for guyed steel stacks of different diameters are given in Table I. For each diameter a minimum and a maximum plate thickness are suggested with corresponding rivet diameters. If durability and permanence are desired, the thicker plate should be chosen for a given stack. Through the action of flue gases and atmospheric moisture, corrosion is very likely to attack the steel stack unless its surface is protected. It is, therefore, recommended that the stack be painted frequently with a good grade of metal paint.

PROPORTIONS OF CHIMNEYS

30. Requirements of Chimney.—The height of a chimney must be such as to produce the proper draft in the furnace, and the diameter must be such as to enable the chimney to carry off the gases from the boiler or boilers. The chimney may have a circular or a square flue, but the circular form is considered more efficient than a square one of equal area, because its inside surface offers less resistance to the passage of the gases, and there is less likelihood that eddies will be formed. There is much difference of opinion among engineers as to whether a stack should be narrower toward the top or increased in size. The usual practice is to taper a stack toward the top, this being done more on account of the necessity for increasing its stability than because of the draft. Some stacks have been built, however, with a larger inside diameter at the top than at the bottom, the idea being to provide a greater sectional area for the passage of the gases as their velocity is decreased.

31. The top of a chimney should extend above nearby buildings, trees, hills, etc., so that air-currents sweeping over such adjacent elevations will not be deflected downwards on top of the chimney and interfere with the draft it produces. The minimum height of a chimney depends on the kind of fuel burned in the boiler. Fine anthracite requires a strong draft and, therefore, a high chimney; bituminous coal requires a chimney of medium height; oil fuel requires less draft than coal, and, therefore, a shorter chimney; and wood requires the least height. Of course, the rate of combustion, the form of the gas passages in the boiler, the length and shape of the breechings, and the number of boilers also have a bearing on the height of the chimney. Because of the expense of construction, it is not economical to build chimneys more than about 200 feet high. Except in cases where the surrounding conditions require a chimney of unusual height, it is better to build two or more chimneys, and to make each of them shorter than a single chimney would need to be.

32. Height of Chimney.—The relation between the height of the chimney and the pressure of the draft, in inches of water, is given by the following rule:

Rule.—*To find the draft pressure of a chimney in inches of water, divide 7.6 by the absolute Fahrenheit temperature of the outside air and divide 7.9 by the absolute Fahrenheit temperature of the chimney gases; subtract the latter quotient from the former and multiply the difference by the height of the chimney, in feet.*

Expressed as a formula, the rule becomes

$$p=H\left(\frac{7.6}{T_a}-\frac{7.9}{T_c}\right)$$

in which p = draft pressure, in inches of water;

H = height of chimney, in feet;

T_a and T_c = absolute temperature of the outside air and of the chimney gases, respectively.

EXAMPLE.—What draft pressure will be produced by a chimney 120 feet high, the temperature of the chimney gases being 600° F., and of the external air 60° F.?

SOLUTION.—By the formula,

$$p=120\left(\frac{7.6}{460+60}-\frac{7.9}{460+600}\right)=.859 \text{ in.} \quad \text{Ans.}$$

33. To find the height of chimney to give a specified draft pressure, the following rule may be used:

Rule.—*To find the height of a chimney, in feet, divide 7.6 by the absolute Fahrenheit temperature of the outside air, and divide 7.9 by the absolute Fahrenheit temperature of the chimney gases; subtract the latter quotient from the former, and divide the required draft, in inches of water, by the difference of the quotients.*

Expressed as a formula, this rule becomes

$$H=\frac{p}{\left(\frac{7.6}{T_a}-\frac{7.9}{T_c}\right)}$$

EXAMPLE.—Required, the height of the chimney to produce a draft of $1\frac{1}{8}$ inches of water, the temperature of the gases and of the external air being, respectively, 550° and 62°.

SOLUTION.—By the formula,

$$H = \frac{1.125}{\frac{7.6}{522} - \frac{7.9}{1,010}} = 167 \text{ ft. Ans.}$$

34. Area of Chimney.—The height of the chimney being decided on, its cross-sectional area must be designed to carry off readily the products of combustion. The following rules for finding the dimensions of chimneys are in common use:

Rule I.—*To find the effective area of a chimney, in square feet, multiply the horsepower of the boiler or boilers by .3 and divide the result by the square root of the height of the chimney, in feet.*

Rule II.—*To find the effective area of a chimney, in square feet, subtract .6 times the square root of the actual area from the actual area, in square feet.*

Rule III.—*To find the horsepower of boilers a chimney will serve, extract the square root of the height of the chimney in feet and multiply it by 3.33 times the effective area in square feet.*

Rule IV.—*To find the side of a square chimney, in inches, multiply the square root of the effective area, in square feet, by 12, and add 4 to the product*

Rule V.—*To find the diameter of a round chimney, in inches, multiply the square root of the effective area, in square feet, by 13.54, and add 4 to the product.*

These rules may also be expressed in the form of formulas.

Let H = height of chimney, in feet;
P = horsepower of boiler or boilers;
A = actual area of chimney, in square feet;
E = effective area of chimney, in square feet;
S = side of square chimney, in inches;
d = diameter of round chimney, in inches.

Then,

$$E = \frac{.3\,P}{\sqrt{H}} = A - .6\sqrt{A} \qquad (1)$$

$$P = 3.33\,E\sqrt{H} \qquad (2)$$

$$S = 12\sqrt{E} + 4 \qquad (3)$$

$$d = 13.54\sqrt{E} + 4 \qquad (4)$$

Table II has been computed from these formulas.

EXAMPLE 1.—What should be the diameter of a chimney 100 feet high that furnishes draft for a 600-horsepower boiler?

SOLUTION.—By formula **1**,

$$E=\frac{.3\,P}{\sqrt{H}}=\frac{.3\times600}{\sqrt{100}}=18$$

Now using formula **4**,

$$d=13.54\sqrt{18}+4=61.44 \text{ in.} \quad \text{Ans.}$$

EXAMPLE 2.—For what horsepower of boilers will a chimney 64 inches square and 125 feet high furnish draft?

SOLUTION.—By simply referring to Table II, the horsepower is found to be 934. Ans.

35. Maximum Combustion Rate.—The maximum rates of combustion attainable under natural draft are given by the following formulas, which have been deduced from the experiments of Isherwood:

Let F = weight, in pounds, of coal per hour per square foot of grate area;

H = height, in feet, of chimney or stack.

Then, for anthracite burned under the most favorable conditions,

$$F=2\sqrt{H}-1 \qquad (1)$$

and under ordinary conditions,

$$F=1.5\sqrt{H}-1 \qquad (2)$$

For best semianthracite and bituminous coals,

$$F=2.25\sqrt{H} \qquad (3)$$

and for less valuable soft coals,

$$F=3\sqrt{H} \qquad (4)$$

The maximum weight of combustion is thus fixed by the height of the chimney; the minimum rate may be anything less.

The foregoing formulas may also be expressed in the form of a rule, as follows:

Rule.—*To find the maximum weight of coal that can be burned per square foot of grate area per hour, with natural draft: Subtract 1 from twice the square root of the chimney height, in feet, for anthracite burned under the most favorable conditions; subtract 1 from 1.5 times the square root of the*

chimney height for anthracite burned under ordinary conditions; multiply the square root of the chimney height by 2.25 for semi-anthracite and bituminous coals; and multiply the square root of the chimney height by 3 for less valuable soft coals.

EXAMPLE.—Under ordinary conditions, what is the maximum rate of combustion of anthracite coal if the chimney is 120 feet high?

SOLUTION.—By formula **2**,

$$H = 1.5\sqrt{120} - 1 = 15.4 \text{ lb. per sq. ft. per hr.} \quad \text{Ans.}$$

36. It will be observed that in Table II the capacity of the stack is given in horsepower. In calculating this table it was considered that 5 pounds of coal was burned to develop 1 horsepower, this being a high figure with the present economical systems of power generation. Allowance has also been made, in this table, for the friction of the gases against the side walls of the stack, it being considered that a 2-inch layer of dead air exists between the stack lining and the gases; that is, the air and gases for a thickness of 2 inches next the walls of the stack are assumed to have no movement, or circulation.

EXAMPLES FOR PRACTICE

1. What should be the height of a chimney to give a draft pressure of $\frac{5}{8}$ inch of water, the temperature of the air being 60° F. and of the gases 440° F.? Ans. 107 ft.

2. A chimney is 135 feet high and 5 feet square inside; calculate the horsepower for which it will furnish draft. Ans. 851 hp.

3. What is the maximum rate of combustion of best bituminous coal in a marine boiler with chimney stack 100 feet high? Ans. 22.5 lb.

4. Calculate the side of a square chimney 150 feet high that furnishes draft for boilers of 1,000 horsepower. Ans. 63.4 in.

5. What draft pressure will a chimney 80 feet high furnish, the temperatures of the air and gases being, respectively, 60° and 600° F.? Ans. .57 in.

6. Under the most favorable conditions, what height of chimney will allow a maximum rate of combustion of anthracite coal of 23 pounds per square foot of grate per hour? Ans. 144 ft.

TABLE II

SIZES OF CHIMNEYS AND HORSEPOWER OF BOILERS

Height of Chimney, in Feet											Effective Area Square Feet	Actual Area Square Feet	Side of Square Inches	Diameter Inches
50	60	70	80	90	100	110	125	150	175	200				
Commercial Horsepower														
23	25	27									.97	1.77	16	18
35	38	41									1.47	2.41	19	21
49	54	58	62								2.08	3.14	22	24
65	72	78	83								2.78	3.98	24	27
84	92	100	107	113							3.58	4.91	27	30
	115	125	133	141							4.47	5.94	30	33
	141	152	163	173	182						5.47	7.07	32	36
		183	196	208	219						6.57	8.30	35	39
		216	231	245	258	271					7.76	9.62	38	42
			311	330	348	365	389				10.44	12.57	43	48
			402	427	449	472	503	551			13.51	15.90	48	54
			505	539	565	593	632	692	748		16.98	19.64	54	60
				658	694	728	776	849	918	981	20.83	23.76	59	66
				792	835	876	934	1,023	1,105	1,181	25.08	28.27	64	72
					995	1,038	1,107	1,212	1,310	1,400	29.73	33.18	70	78
					1,163	1,214	1,294	1,418	1,531	1,637	34.76	38.48	75	84
					1,344	1,415	1,496	1,639	1,770	1,893	40.19	44.18	80	90
					1,537	1,616	1,720	1,876	2,027	2,167	46.01	50.27	86	96

DRAFT

METHODS OF PRODUCING DRAFT

37. Natural Draft.—The hot gases that escape into the chimney from the boiler may have a temperature of from 250° to 650° F., whereas the air outside usually has a temperature below 90° F. Thus, the gases inside the chimney are lighter than the air outside; that is, they weigh considerably less per cubic foot. As a result, they rise in the chimney and the heavier outside air flows in to take their place. If the boiler setting and the connections are in good condition, the outside air can enter only through the furnace; thus a continuous current is set up, fresh air flowing through the fuel bed into the furnace and the gaseous products of combustion passing over the heating surface and out through the chimney to the air. This movement of air and gases is called *draft,* and when it is produced only by the relative lightness of the gases inside the chimney and the air outside, without the aid of any appliances, it is known as natural draft.

38. Draft is caused by a difference of pressure. Suppose that hot gases at a temperature of 500° F. flow into a chimney 150 feet high. A column of such gases 150 feet high and 1 square foot in cross-section weighs approximately 6½ pounds. A column of air of the same height and cross-section, at a temperature of 60° F., weighs about 11½ pounds. The difference of weight is 5 pounds; hence, the pressure at the base of the chimney is greater outside than inside by about 5 pounds to the square foot of area of cross-section. Flow of gases or liquids always takes place from the point of higher pressure to the point of lower pressure, and it is this difference of pressure of 5 pounds per square foot that causes the outside air to flow into the furnace and thence by way of the boiler passages to the chimney. The difference of pressure inside and outside the chimney, at its base, is called the *draft pressure.*

39. Measurement of Draft Pressure.—The intensity of the draft, or the draft pressure, is usually only a small fraction

of a pound to the square inch; therefore, draft pressures are not expressed in pounds per square inch, but in inches of water. In other words, the draft pressure is measured by the height of a column of water that will produce a pressure equal to the draft pressure. A column of water 34 feet high and 1 square inch in cross-section weighs 14.7 pounds; that is, the pressure at the foot of such a column is equal to atmospheric pressure. As 34 feet is equivalent to 408 inches, a column of water 1 inch high has a pressure at its base of $14.7 \div 408 = .036$ pound per square inch. Thus, if a draft pressure is said to be $1\frac{1}{4}$ inches of water, the difference of pressure is $1\frac{1}{4} \times .036 = .045$ pound per square inch. The **U** gauge, shown in Fig. 21, may be used to measure draft pressure. As will be seen, it is a glass tube bent to the shape of the letter **U**. The left leg communicates with the chimney, and the right leg at the top is open to the outside air. The air outside the chimney being heavier, it presses on the surface of the water in the right leg and forces some of it up the left leg. The difference in the two water levels h and z in the legs represents the intensity of the draft and is expressed in inches of water.

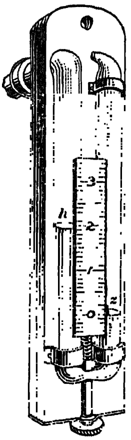


FIG. 21

40. Mechanical Draft.—Under certain conditions it may be out of the question to use natural draft. For example, certain kinds of fuel require very high draft pressure in order to force the necessary amount of air through the fire. The cost of a chimney of sufficient height to supply the required draft may be so great as to make it impracticable to use natural draft. Again, there may not be sufficient room to build a chimney of the desired capacity. In such cases, the draft may be produced by appliances, such as fans, blowers, or steam jets. Draft produced by these means is called mechanical draft to distinguish it from natural draft. It may be either *forced draft* or *induced draft*. With forced draft, the air is forced into the ash-pit under pressure; with induced draft, a partial vacuum is formed at the chimney, and the air and gases are

drawn through the furnace and boiler passages instead of being forced through.

41. Advantages and Disadvantages of Mechanical Draft. Forced draft has certain advantages for a number of installations and conditions. It produces sufficient air pressure to force air through very thick fuel beds, and is, therefore, of great advantage in burning fuel with underfeed stokers and where hollow grates are used. When anthracite screenings are burned, the tendency of the fuel is to cake and form clinker on the grate; but from the intensity of forced draft, this tendency is overcome. The disadvantage of forced-draft systems is that when the air is forced into the boiler setting under high pressure, some of it escapes through the fire-doors and ash-pit doors, and through other openings in the furnace walls. The fire and ash-pit cannot be cleaned when the blast is on, for the reason that soot, smoke, and ash dust would be blown out into the boiler room.

42. Induced draft tends at all times to draw the air into the furnace and stack and thus affords a means of ventilating the boiler room. The firing and cleaning operation may be carried on without the objections of smoke and dust. By this system a uniform condition of the fuel bed can be obtained. It is efficient where an economizer is used, as it makes up the draft loss in the stack due to the reduction of flue-gas temperature that occurs when the gases give up their heat to the water in the economizer. When head room is limited and the breeching is large, it is sometimes difficult to install the induced-draft system. However, since it utilizes the space above the boilers, it is out of the way and makes it possible to use ground floor space that would be taken up if forced draft were used. The steam consumption of a blower system producing either induced or forced draft varies from 2 to 5 per cent. of the steaming capacity of the plant.

EQUIPMENT FOR MECHANICAL DRAFT

43. Fans and Steam Jets.—For forcing air under pressure into the ash-pit, either a fan or a steam jet may be used. Steam jets are not favored to any great extent and their use in modern boiler plants is limited. With some fuels, live steam is introduced under the grate to prevent the forming of large clinkers. The steam in passing through the fuel bed is broken up into its two elements, hydrogen and oxygen, and the heat taken from the fuel bed to produce this dissociation cools the lower bed of fuel sufficiently to prevent large clinker formation. It also tends to prevent the grates from overheating. A steam jet has a lower first cost than a fan blower, but the latter is preferable, as it produces better results in the combustion of fuels.

44. A common construction of fans is shown in Fig. 22 (*a*) and (*b*). The shell or housing *a* is made of steel plate,

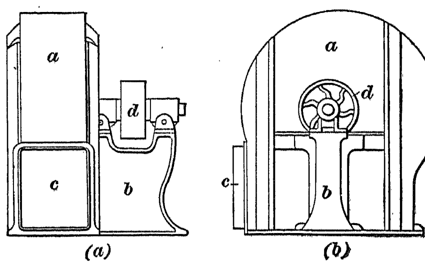


FIG. 22

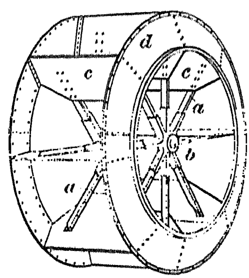


FIG. 23

with a substantial base *b* of cast iron or wrought iron. An outlet *c* is placed at the desired point of the circumference, whence the air is discharged into the duct leading to the ash-pit. In the fan shown there is one inlet, which surrounds the fan shaft on the side opposite the pulley *d* through which the fan is driven. The fan shaft is supported in two bearings and carries the fan wheel within the casing. The usual construction of the fan wheel is shown in Fig. 23. Arms *a* made of **T** iron are fastened to the hub *b* and carry at their ends the blades *c*. These blades are tied together by the side plates *d*.

45. Typical Forced-Draft Installations.—One of the usual methods of installing a forced-draft system for two or more horizontal return-tubular boilers is shown in Fig. 24. The equipment consists essentially of a fan *a* and an engine *b*. The fan may be located above the boilers. in which case the

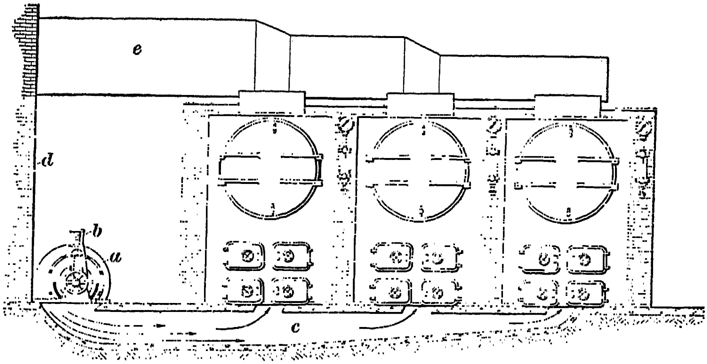


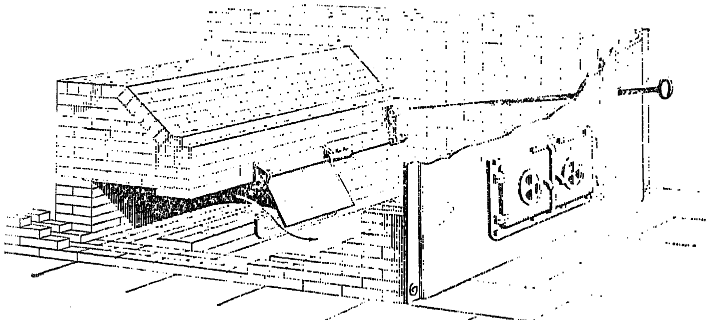
FIG. 24

air is conveyed to the ash-pit by sheet-metal ducts. Ordinarily the fan is set on the floor and discharges into underground concrete air ducts *c*. The air ducts may enter the ash-pit directly under the bridge wall or from the side or rear of the setting, as conditions permit. Where a number of boilers are set in a battery and are connected to a common stack *d* by a breeching *e*, it is customary to install an induced-draft fan in the breeching near the stack or else to use a short stack to furnish draft to overcome the friction of the gases in passing from the furnace.

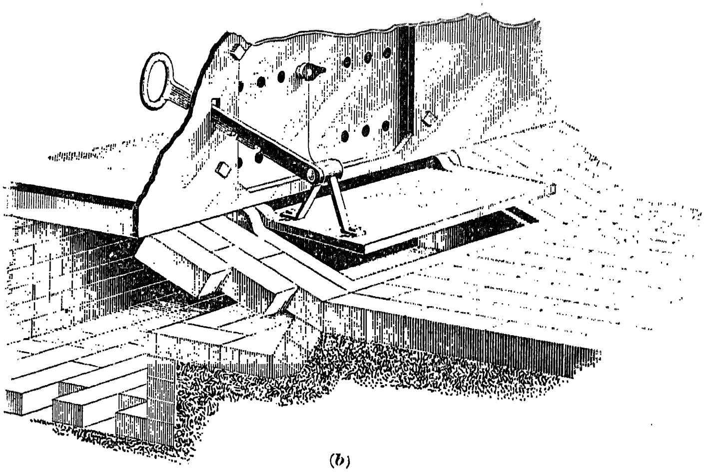
46. Ash-Pit Fixtures for Forced-Draft Installations. The air discharged by the fan may be introduced into the ash-pit through an opening in the bridge wall, and the draft through it may be regulated by a damper as shown in Fig. 25 (*a*). This arrangement is recommended for a new boiler plant. When forced draft is applied to an old plant, the air may be introduced in front through an opening in the bottom of the ash-pit, as shown in (*b*). When the damper is closed, the

ashes may readily be raked over it. The damper, when opened, serves to distribute the air thoroughly in the ash-pit.

Concrete air ducts are the most durable, but when low first cost is essential, galvanized iron ducts may be used; in such a



(*a*)



(*b*)

FIG. 25

case it is customary to have the main supply overhead and a branch pipe extending down to each boiler.

47. Horsepower Required for Producing Forced Draft. The horsepower necessary to furnish forced draft may be calculated by the following rule:

Rule.—*To find the horsepower required to furnish forced draft, divide the product of the draft pressure, in pounds per square foot, the weight of fuel burned per minute on the grate, in pounds, and the volume of air, in cubic feet per pound of fuel, by the product of 33,000 times the efficiency of the draft apparatus, expressed as a decimal.*

Expressed as a formula, the rule becomes

$$P = \frac{p\,W\,V}{33{,}000\,y}$$

in which P = horsepower required;
p = pressure of draft, in pounds per square foot;
W = total weight of fuel, in pounds, burned on grate per minute;
V = volume of air, in cubic feet per pound of fuel;
y = efficiency of draft apparatus.

EXAMPLE.—What horsepower is required to supply air at a pressure of 2½ inches of water to a total grate area of 120 square feet burning 20 pounds of coal per square foot per hour and requiring 220 cubic feet of air per pound of coal? Assume the efficiency to be 60 per cent.

SOLUTION.—By the formula,

$$P = \frac{p\,W\,V}{33{,}000\,y} = \frac{2\tfrac{1}{2}\times 5.2\times \tfrac{20}{60}\times 120\times 220}{33{,}000\times .60} = 5.78 \text{ hp.} \quad \text{Ans.}$$

48. Turbine Blower.—The turbine blower forms an efficient and a satisfactory means of forcing air into the furnace through the fuel bed from the ash-pit. As shown in Fig. 26 (*a*) and (*b*), it consists of a bladed fan *a*, shaped like a ship's propeller, connected to a shaft *b* on which is fixed the rotor of a turbine inside the casing *c*. The rotor, or turbine wheel, is driven by steam that enters through the pipe *d*, the exhaust escaping through the pipe *e*. The blower is installed in the wall *f* of the boiler setting, which may be the side, front, or back wall. The rapid rotation of the fan *a* by the steam turbine draws air into the blower and forces it into the boiler setting beneath the fuel bed. The exhaust steam from the blower may be conducted to a feedwater heater or to a heating system; or, a part or all of it may be allowed to pass up through the grates with the air, to prevent clinkering when

coal with a fusible ash is used. The number of blowers required depends on the number of boilers, the rate of combustion of fuel, and the capacity of the blower.

49. Induced-Draft Apparatus.—A typical induced-draft installation for a battery of three boilers is shown in Fig. 27. It consists of a single exhaust fan *a* driven by a steam engine *b* directly connected to the fan shaft. For such installations a

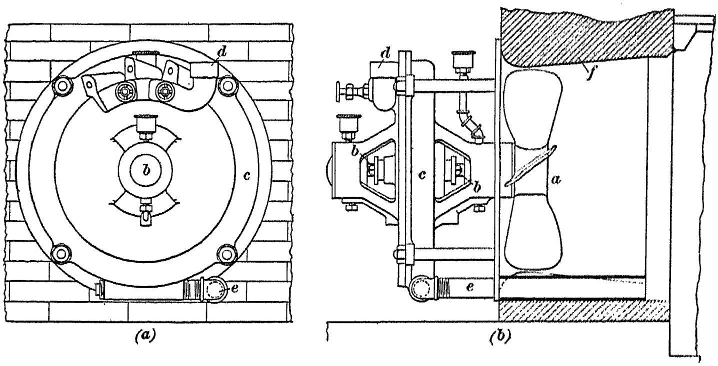


FIG. 26

short stack *c* is directly connected to the fan outlet *d*. A bypass pipe *e* connecting with the breeching *f* and fitted with a damper *g* should always be installed, so as to permit operation with stack draft when starting the fires, when the plant is operating under a light load, or when repairs are required to the fan or the engine. By using induced draft with hand-fired furnaces an increase of boiler capacity up to 200 per cent. of rating may be obtained; and an increase of capacity up to 400 per cent. of rating can be obtained by using forced draft in combination with induced draft. The intensity of draft may be regulated either by hand or by some form of automatic control.

DRAFT CONTROL

50. Balanced Draft.—A system of combined forced draft and induced draft has been worked out, in which the fuel feed, the air supply, and the stack draft are all automatically con-

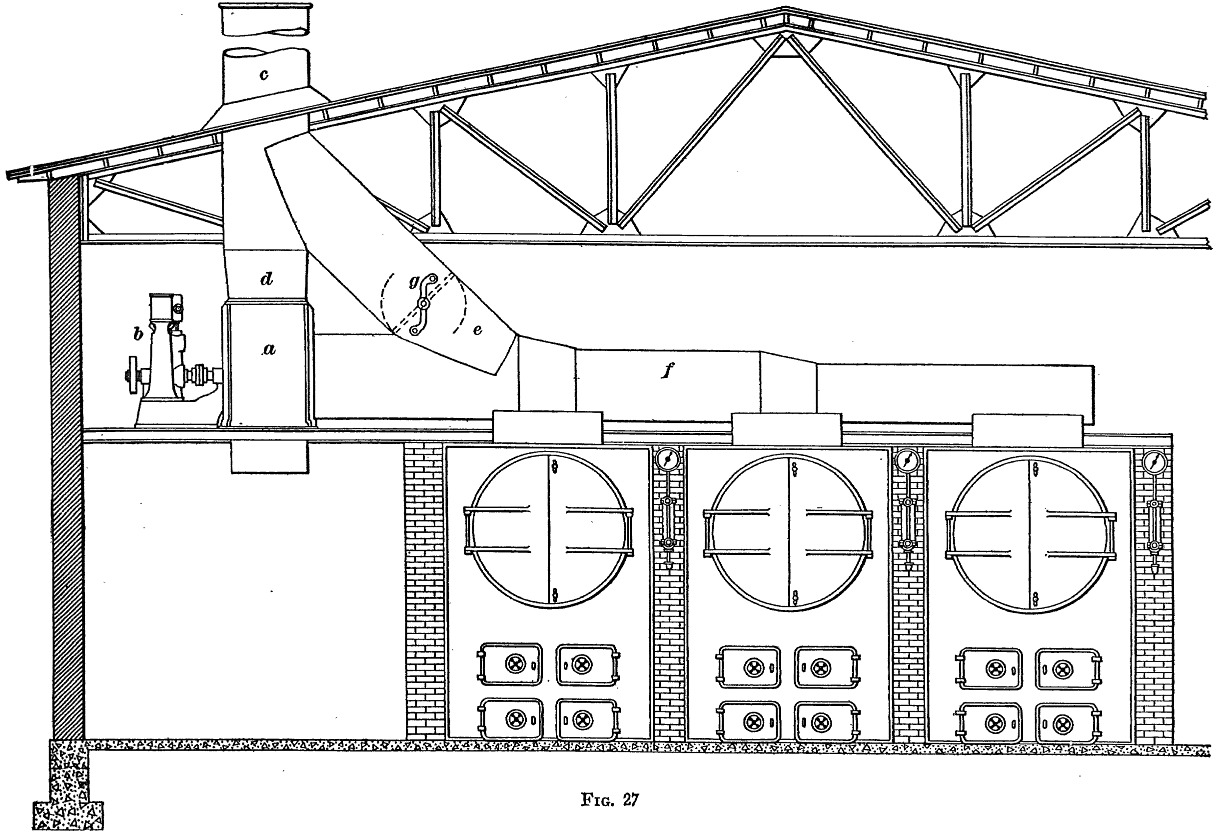


FIG. 27

trolled by an interlocking regulation, so that the combustion conditions are always suited to the condition of the fire. The arrangement of the various regulating devices used in this system is shown in Fig. 28. A fan *a* driven by a steam tur-

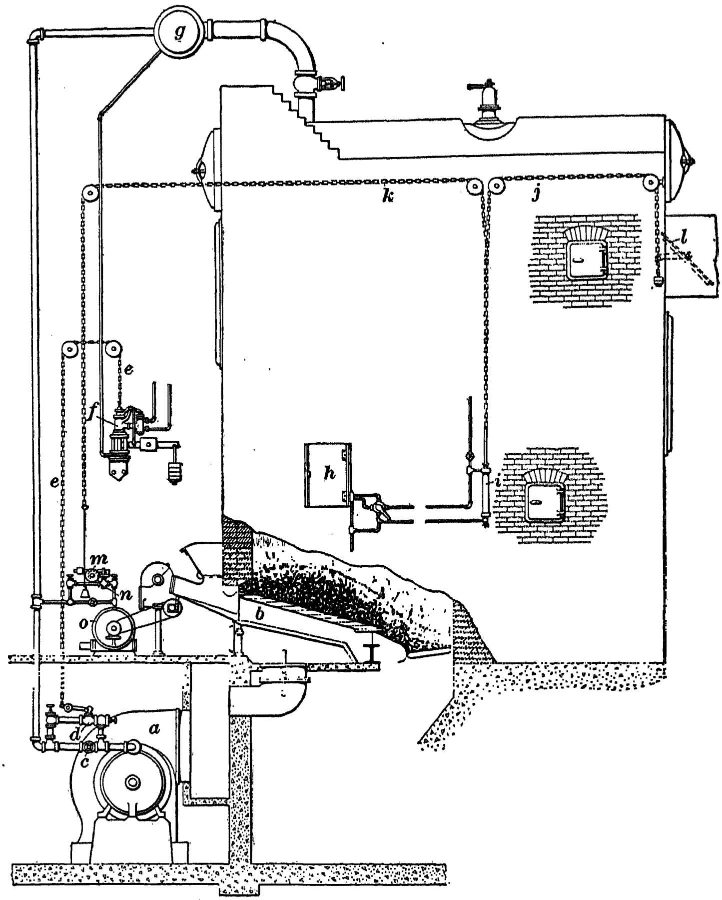


FIG. 28

bine supplies air under pressure beneath the grates *b* and thus enables the air to overcome the resistance due to the thickness of the fuel bed. The minimum speed of the turbine driving the fan is fixed by the amount of opening of the valve *c* in the

steam-supply pipe. In addition, there is a by-pass containing a valve *d* connected by a chain *e* to the piston of the regulator *f*, which has a diaphragm subjected to the pressure of the steam in the steam main *g*. Any change of steam pressure causes movement of the regulator piston and thus moves the valve *d*, admitting either more or less steam to the turbine and thus altering the fan speed, and consequently the quantity of air supplied beneath the grates.

51. At the side of the boiler setting, Fig. 28, is a furnace pressure regulator. Inside the casing *h* is a pivoted blade or leaf that swings in a chamber communicating by a tube with the furnace. If the pressure in the furnace changes even slightly, this blade is swung on its pivot. Connected to the blade by levers is a pilot valve that controls the flow of water under pressure to the upper or lower end of the cylinder *i*. This cylinder contains a piston to which the chains *j* and *k* are attached. The chain *j* leads to the damper *l* and the chain *k* to a cam *m* on the valve *n* that controls the steam supply to the stoker engine *o*. Thus, the damper position and the rate of feed of the fuel are both automatically altered in case the pressure in the furnace changes.

Suppose that the steam pressure drops slightly. The regulator *f* opens the valve *d* slightly and the fan speeds up, increasing the air supply. The combustion becomes more rapid, producing more gases in the furnace, and the draft over the fire tends to decrease. This causes the blade in the regulator *h* to move and so the piston in the cylinder *i* is moved, opening the damper enough to restore the draft above the fire. At the same time the cam *m* is moved, opening the valve *n*, speeding up the stoker engine, and consequently the rate of fuel feed.

52. Automatic Damper Regulators.—In steam power plants, the aim is to promote economic combustion of the fuel and to maintain uniform steam pressure. For this purpose automatic damper regulators are used, which depend for their operation on a change in the steam pressure. The Spencer hydraulic damper regulator, shown in Fig. 29, illustrates one means of regulating the draft. The chamber *b* contains a

flexible diaphragm dividing the chamber into two parts. The under part is filled with water subjected to the boiler pressure through the steam pipe *d*. The diaphragm tends to move upwards under the influence of the steam pressure, but its upward motion is resisted by the downward force exerted by the weighted lever *c*. The weights are so adjusted that the lever will occupy a position midway between its two extreme

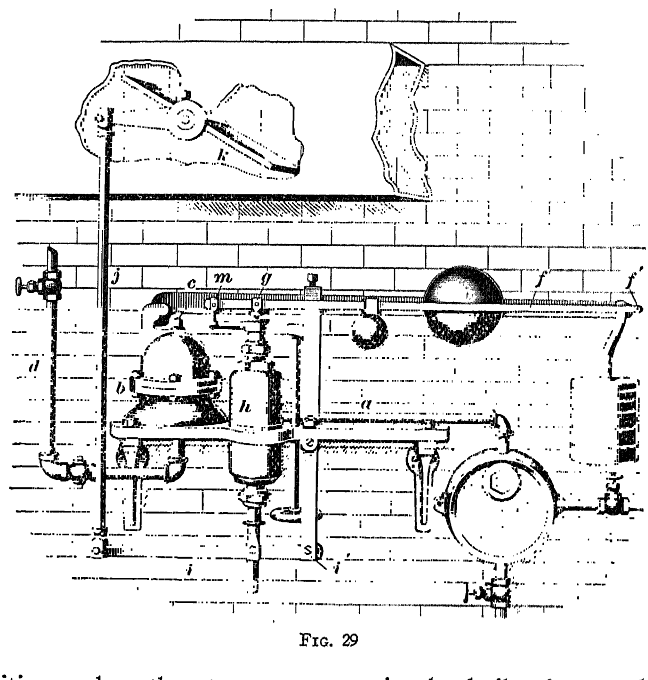


FIG. 29

positions when the steam pressure in the boiler is exactly at the point at which it is to be carried. A secondary lever *f* is hinged at *f'* to the free end of the lever *c*. The secondary lever is fulcrumed at *m*, and at *g* the valve stem of the operating valve is attached to it. This valve works inside a piston that is closely fitted to the stationary cylinder *h*, the valve serving to admit water under pressure to either side of the piston. The piston rod passes through both heads of the cylinder *h*; at its lower extremity it is connected to the lever *i* pivoted at *i'*,

which, through the medium of the connecting-rod *j*, transmits any motion of the piston to the damper *k*.

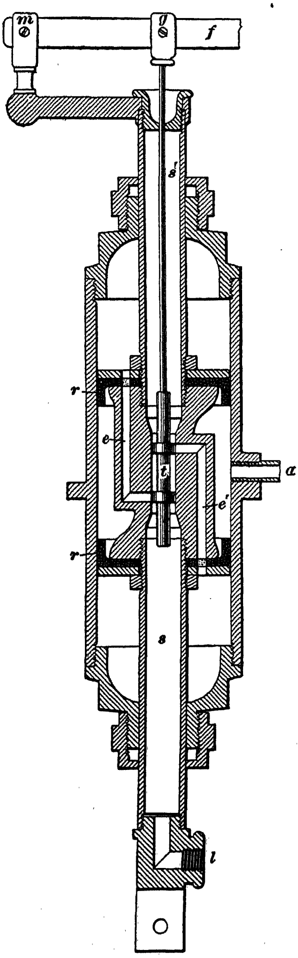


FIG. 30

53. Let the steam pressure rise above that for which the damper is set. Then the diaphragm and the free end of the lever *c*, Fig. 29, move upwards. The lever *f*, being connected at *f'*, swings upwards around *m* as a fulcrum; this raises the valve inside of the cylinder *h* and thus admits water under pressure from the pipe *a* to the bottom of the piston in the cylinder *h*. At the same time, the valve places the upper side of the cylinder in communication with a water-escape pipe. In consequence thereof, the piston ascends and pulls the lever *i* upwards, which in turn rotates the damper *k*, closing it still farther. As the piston ascends, the fulcrum *m* is moved upwards and the lever *f* swings around *f'* as a fulcrum, causing the valve in the piston to move downwards in relation to the piston, closing the water-supply port and holding the piston in its new position. When the steam pressure falls below normal, the levers *c* and *f* descend, and as the lever *f* swings around *m*, the valve also descends, placing the upper side of the piston in communication with the water supply and the under side in communication with the water-escape pipe. Then the piston descends and the damper opens. But the lever *f* now swings around *f'*, and thus causes the valve to ascend in relation to the piston, which is then brought to rest.

54. The cylinder *h*, Fig. 29, is shown in section in Fig. 30. The piston is made water-tight by the cup leather packing rings *r*. The water under pressure enters through the supply pipe *a* and surrounds the piston, entering through a small port into the central valve chamber and then surrounding the central part of the piston valve *t*. When the valve moves upwards

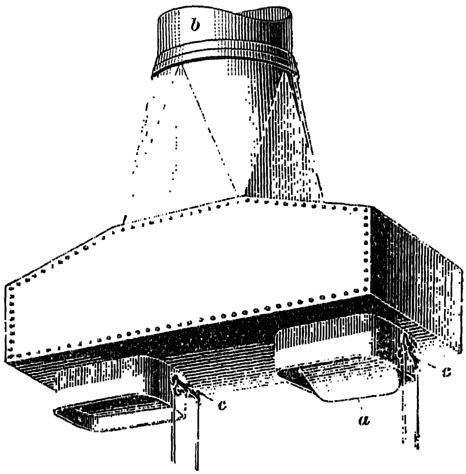


FIG. 31

it uncovers the ports *e′* and *e*; the water under pressure flows through the port *e′* into the lower part of the cylinder; at the same time the water in the upper parts flow through the port *e* into the hollow piston rods *s* and out at *l*. The resultant motion of the piston then returns the valve to the central position shown. If the valve descends, it admits the water into the port *e* and allows the water in the lower half of the cylinder to escape through the port *e′* into the passage *s′*, which, through a by-pass port not shown, communicates with the passage *s*. The descent of the piston again returns the valve to its central position.

55. Hand-Operated Draft Regulator.—In Fig. 31 is shown a breeching with hand-operated dampers, as used in some power plants. The damper consists of a plate *a*, which may be placed in either the uptakes or in the stack *b*. The plate is fastened to the damper rod, and is opened or closed by

chains attached to the lever *c*. The damper reduces the draft area and thus the volume of gases escaping into the chimney, and so retards the flow of air through the fire into the furnace. This reduction in the air supply reduces the intensity of the fire and the generation of steam. Dampers are also fitted in ash-pits so as to regulate the amount of air admitted under the grates.

OTHER DRAFT-PRODUCING DEVICES

56. Steam Jets.—In hand-fired furnaces steam jets are often used to mix the fuel gases and the air. A larger amount of air is required in a furnace at the time of firing the fuel than during the distillation of the volatile matter in the fuel bed. Several automatic devices for introducing steam and air into the furnace have been patented, and one of them is shown in

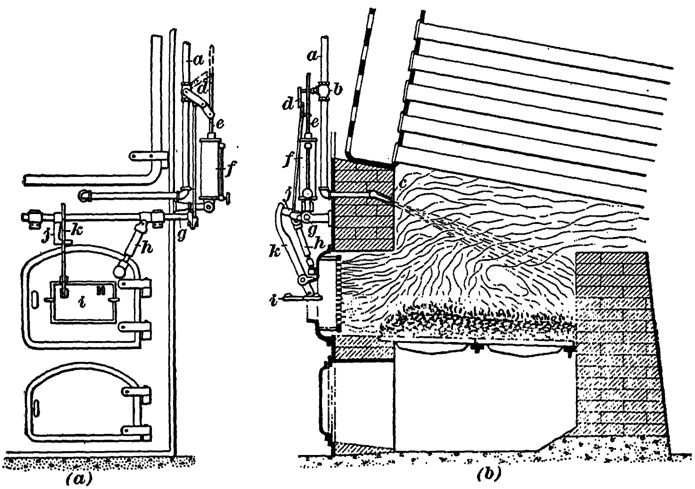


FIG. 32

Fig. 32 (*a*) and (*b*). It consists of a steam pipe *a*, fitted with a valve *b*, through which steam is admitted from the boiler to a number of steam jets *c* arranged in a horizontal row across the front of the furnace, so that the steam flows into the furnace at an angle to the fuel bed. The valve *b* is connected to a

lever *d* that is fastened to the piston rod *e* of a piston that fits inside the dash-pot *f*. The lever *d* is connected by a crank to the shaft *g*, which in turn is connected to the fire-door by a rod *h* and a crank. The fireman in opening the fire-door causes the shaft *g* to turn, which in turn operates the lever *d* and thus opens the valve *b*, allowing steam to enter through

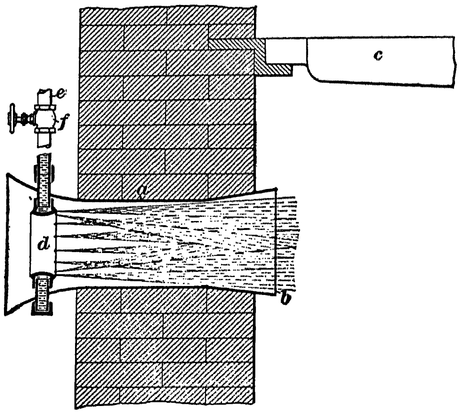


FIG. 33

the jets *c*. The air door *i* is also opened at the same time by the turning of the shaft *g*, which carries a dog *j* that presses against the lever *k*. Steam and air are admitted for some time after the fire-door is closed; but during this period the dash-pot piston automatically descends, gradually moving the lever *d*, turning the shaft *g*, and thus closing the valve *b* and the air door *i*. The advantage of this device is that the gases and the air are intimately mixed during the period in which the volatile matter is being driven off from the fresh fuel, thus preventing smoke and saving fuel.

57. Argand Blower.—The Argand blower, shown in Fig. 33, is a device for producing a supply of air under pressure in the ash-pit and is operated by steam jets. It consists of a long air tube flared at both ends and inserted through the front wall of the setting, so that the inner end *b* is beneath the forward end of the grates *c*. At the outer end is a hollow

ring *d* perforated with numerous holes on the side toward the ash-pit and supplied with steam through the pipe *e* and the valve *f*. When steam is admitted to the ring *d*, it escapes through the perforations in many small jets, as shown, drawing air in at the outer end, and carrying it along into the ash-pit.

58. Induced Draft by Steam Jet.—Increased draft in the furnace and boiler passages may be obtained by inserting a steam-jet blower at the base of the stack, as shown in Fig. 34. The blower consists of a nozzle *a* held in place in the center of

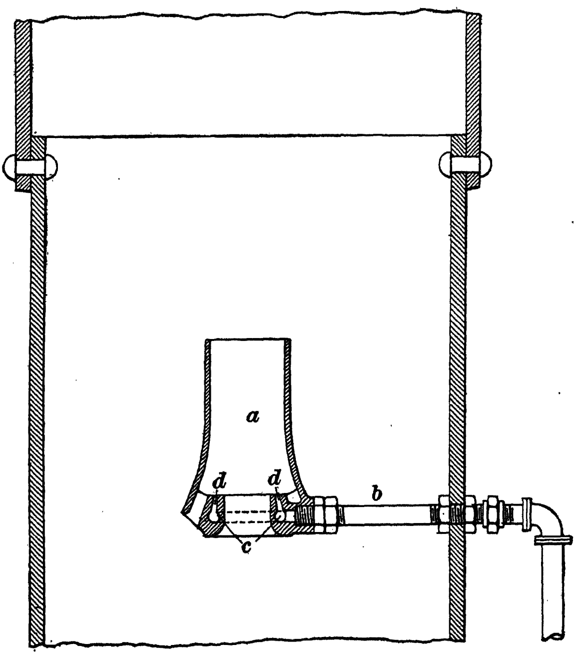


FIG. 34

the stack by the piping *b* through which steam is supplied. The steam enters an annular passage *c* in the base of the blower, from which it escapes through the orifices *d* into the nozzle, drawing gases through the nozzle and discharging them at the top and thus producing a strong upward current in the stack.